VOL. 3 No. 5 MAY 1938

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, HOLLAND

# FLUORESCENCE

by W. DE GROOT.

535.37

In this article an attempt is made to give a survey of the phenomena of fluorescence by beginning with the simplest case, the fluorescence of metal vapours, and passing on to phenomena of a more complex character. The fluorescence of the following substances is discussed: monatomic (Na, Hg, Ne) and molecular gases ($I_2$), solid substances (uranyl compounds) and liquids (fluorescein, eosin).

## Introduction

The discovery of the phenomena of fluorescence and phosphorescence dates from the renaissance. It was the shoemaker-alchemist Casciarolus who discovered phosphorescence in 1602, when he heated a barite in the fire and obtained a substance which, after having been exposed to the light continued to glow with a red light in the dark. In the case of fluorescence it may be noted that Grimaldi in 1665 found that an extract of lignum nephriticum, a wood then considered to possess healing properties, is yellow by transmitted light and blue by reflected light (seen against a dark background). The blue colour had already been described by Monardes in 1575.

Fluorescence is the property of a substance of radiating energy which it has absorbed, in the form of light usually with an altered spectral composition. Phosphorescence is generally used to describe the phenomenon when the substance continues to radiate light for a long time after it has been irradiated.

The development of physics and chemistry in the nineteenth century learned to know a large number of fluorescent substances. Kayser's well-known handbook (IV, 1908) gives more than one thousand, among which many organic compounds. Phosphorescent substances were first investigated in detail and prepared in large numbers by Lenard and his students (1894). The importance of all these substances, the fluorescent as well as the phosphorescent, in the technique of lighting has become steadily greater, particularly in connection with the increasing use of gas discharge lamps. In addition to the visible, and therefore directly useful, radiation, an appreciable amount of invisible ultra-violet radiation is emitted by such lamps, particularly those which contain mercury vapour. With the aid of fluorescent and phosphorescent substances it is possible to transform a portion of this invisible radiation into visible light, and in that way to improve the lighting efficiency of the lamp. The substances mentioned are also important because of the fact that the visible light which they emit differs in spectral composition from that of the discharge lamp itself, and therefore offers the possibility of changing the colour of the light and adapting it to a given purpose.

It is our intention to discuss later some of the properties and the technical applications of the fluorescent and phosphorescent substances now in use, after we have given first an account of the physical side of the phenomena under consideration.

## Fluorescence of gases (resonance)

The simplest case of fluorescence is that of substances in the gaseous state, especially monatomic gases. Let us for example consider the vapour of the metal sodium. This vapour consists mainly of sodium atoms which move about quite independently of each other.

It was previously explained (Philips techn. Rev. 1, 2 - 5, 1936) how, according to the concepts of the quantum theory, an atom may be not only in the lowest state of energy, but also in various higher energy states (excited states). *Fig. 1* gives the energy level diagram (term scheme) of the sodium atom; several of the most important energy states are given in the figure with their energy content expressed in electron volts (1 electron volt, often simply called volt, is equal to $1.6 \times 10^{-12}$ erg). It may be seen from this diagram that in addition to the normal or lowest state there is an important energy level at 2.1 electron volts. Upon transition from this state to the lowest state the atom can emit a light quantum with an energy of:

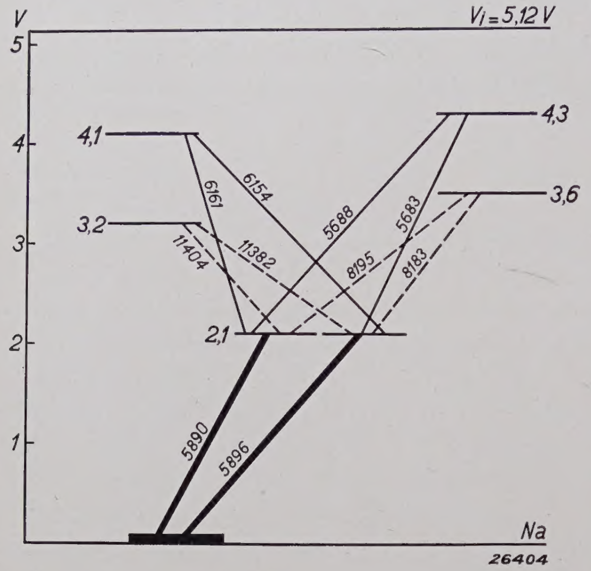


Fig. 1. Energy level diagram of a sodium atom. The lines indicate possible transitions (broken lines lie outside the visible part of the spectrum). The numbers indicate the wave length in Å of the spectrum line corresponding to the transition.

$$2.1 \cdot 1.6 \cdot 10^{-12} = 3.96 \cdot 10^{-12} \text{ erg}.$$

The wavelength in Ångstrom units of the light emitted can be found from the formula [1])

$$\lambda_{\text{Å}} = 12390/V_{\text{volts}}.$$

In this case the wave length is 5890 Å; as a matter of fact the 2.1 volt level is double, and there are two lines with wave lengths 5890 Å and 5896 Å, the two D-lines of the sodium spectrum, which are also responsible for the yellow colour of the sodium flame and the yellow light of sodium lamps.

Let us now imagine the following experiment (*fig. 2*). *L* is a light source in which sodium atoms are made to emit the D-lines, for instance a sodium lamp. Part of the light from *L* is concentrated by a lens *l* on a bulb made of a glass resistant to sodium and containing metallic sodium. The bulb is maintained at a temperature of about 200° C by an oven *O*. We then see that the bundle of rays stands out inside the bulb as a cone of yellow light. Experiments like this were first carried out by R. W. Wood in 1905. On the basis of the then prevailing conceptions about the emission and absorption of radiation this phenomenon, which was termed resonance, was considered to be due to the sympathetic vibration of the oscillators present in the vapour atoms with the light waves sent out from *L*, in the same way that a tuning fork vibrates when a nearby tuning fork of the same pitch emits sound waves. The name resonance has been retained, although the explanation of the phenomenon is at present different. According to the quantum theory it must be assumed that the atoms in the light source pass from the 2.1 volt states to the lowest state. These atoms had reached a 2.1 volt state by taking up energy from the electrons which had obtained a certain kinetic energy in the positive column of the sodium lamp under the influence of the electric field. They radiate the energy taken up in the form of light quanta which are absorbed by the vapour atoms in the bulb *B*, so that the latter now reach the 2.1 volt state. These atoms will in turn almost immediately radiate the energy taken up again, and this radiation is the resonance light observed. If a foreign gas, nitrogen for instance, is added to the sodium vapour, the intensity of the resonance light is diminished. This may be interpreted to mean that the sodium atoms in the 2.1 volt state can give their energy to a nitrogen molecule by collision. The nitrogen molecule either moves forward (energy of translation) or it takens on a vibratory motion (energy of vibration) in which the two nitrogen atoms of the molecule vibrate with respect to each other. The sodium atoms then return to the lowest state without having radiated any light.

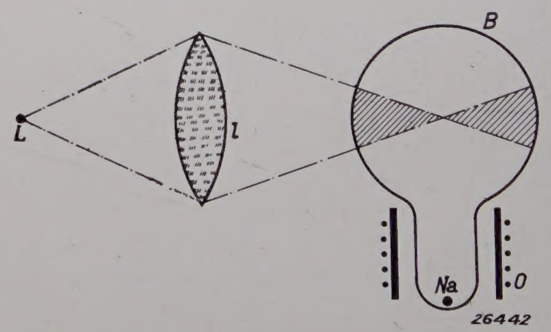


Fig. 2. Resonance radiation of sodium vapour. *L* light source, *l* lens, *O* oven, *B* bulb in which sodium (Na) is evaporated.

## Resonance in mercury vapour

While for the case discussed above (sodium) it seems to be a matter of indifference whether one chooses the theoretical quantum or the older classical interpretation of the phenomenon of resonance, in more complicated cases, several of which we shall now discuss, the great advantage of the quantum theory becomes evident.

---

[1]) In the quoted article of G. Heller the number 12340 is given; since for the fundamental physical constants *e* and *h* some slightly changed values are adopted, through which this number is somewhat changed.

Let us consider the energy diagram of the mercury atom (*fig. 3*). In this case we encounter three states of energy above the lowest state with energies of 4.7, 4.9 and 5.45 electron volts. From the lowest state the atom can pass into the 4.9 volt state by the absorption of an ultraviolet quantum of a wave length of 2537 Å. By letting light of this wave length fall on mercury vapour in a quartz bulb resonance may be observed in the same way as with sodium. The observation must be photographic in this case and not visual, since the eye is not sensitive to radiation of a wave length of 2537 Å.

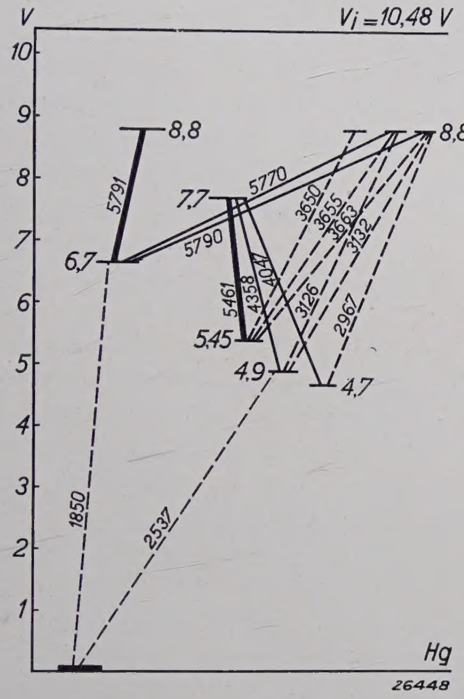


Fig. 3. Energy level diagram of a mercury atom.

If we consider the energy scheme of mercury more closely, we see that an atom in the 4.9 volt state can, by absorption of a quantum of violet light with a wave length of 4358 Å, pass over into a still higher state (7.7 electron volts), while it not only can return to the 4.9 volt state with the radiation of 4358 Å, but also to the 5.45 volt and the 4.7 volt state with the radiation of a green or a violet quantum respectively (wave lengths 5461 and 4047 Å). Wood irradiated mercury vapour with light of the wave lengths 2537 and 4358 Å simultaneously, and saw that the vapour began to radiate the green line 5461 Å (*fig. 4*). This shows that an atom which has absorbed 2537 Å remains in the 4.9 volt state long enough to have the opportunity of absorbing a quantum of 4358 Å. This experiment would be difficult to explain with the conception of oscillators.

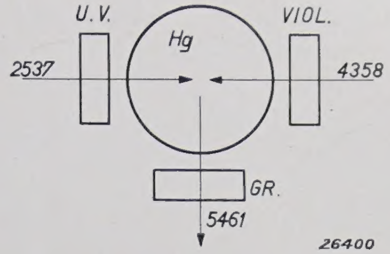


Fig. 4. Composite resonance in mercury vapour according to Wood. *UV* ultraviolet filter, *VIOL* violet filter, *GR* green filter.

When Wood added a neutral gas, such as nitrogen ($N_2$) to the mercury vapour, radiation with 2537 Å then resulted in a strong absorption of the line 4047 Å. The triplet of lines 5461, 4358 and 4047 Å appeared in great intensity (*fig. 5*). This phenomenon may be explained in the following way. The mercury atoms which have attained the 4.9 volt state by absorption of 2537 Å, can pass energy on to a nitrogen molecule by collision, as was the case with sodium. The mercury atom may among other possibilities pass over from the 4.9 volt state to the lower 4.7 volt state. The latter state differs from the states so far discussed in the fact that the atom is unable except to a small degree to return from this state to the lowest state by radiation. The line (2656 Å) corresponding to this transition, which is not drawn in fig. 3, is a so-called forbidden line of the mercury spectrum; this means practically that its intensity is smaller by a factor of $10^6$ than that of corresponding non-forbidden lines. The atom which has once reached the 4.7 volt state therefore will remain in that state much longer than in the 4.9 volt state for instance. The 4.7 volt state is therefore called metastable. Under the conditions of the experiment (irradiation with 2537 Å in the presence of nitrogen molecules), there is an appreciable accumulation of metastable atoms which explains the strong absorption of 4047 Å.

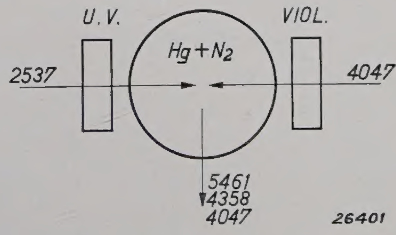


Fig. 5. Composite resonance in mercury vapour mixed with nitrogen according to Wood. *UV* ultraviolet filter, *VIOL* violet filter.

## Resonance in neon

The resonance phenomena in the gas neon are somewhat more complex. *Fig. 6* is a photograph of resonance light in neon. In the lower half of the bulb, which is filled with neon at a pressure of several millimetres, there are two electrodes between which a glow discharge is maintained. If the bulb is irradiated with a horizontal beam of light from a tube which emits red neon light, the result is a beam of red resonance light in which particularly the line 6402 Å dominates (see *fig.* 7). In the glow discharge the two resonance lines of neon (735.7 and 743.5 Å), among others, are excited. This radiation spreads out over the whole bulb and is absorbed by the other neon atoms which thereby attain states of energy of 16.84 and 16.67 volts (see fig. 7).

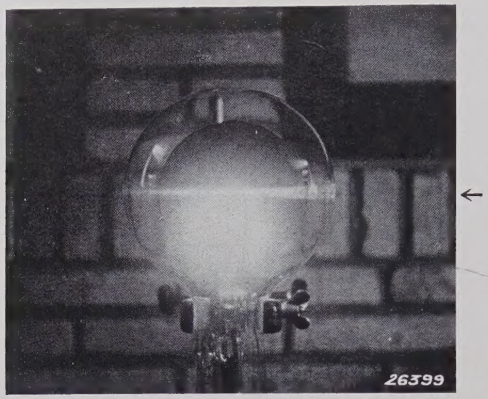


Fig. 6. Resonance light in neon. A horizontal beam of neon light is incident from the right (←).

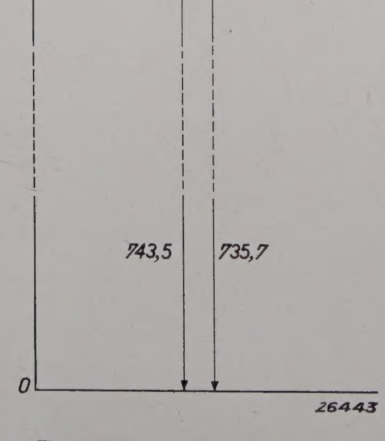


Fig. 7. Energy level diagram of a neon atom.

Meissner and H. B. Dorgelo have shown that under such circumstances various orange and red neon lines are strongly absorbed, namely lines 6402 and 6143 Å, which appear as combinations of the lower metastable level with several energy levels lying around 18.5 electron volts. Considering the absence of foreign atoms or molecules, it must be assumed that in this case the metastable atoms occur by collision between normal neon atoms and atoms which have been brought into the non-metastable 16.67 volt state, for instance, by the absorption of light of short wave lengths. In the collision the latter atoms have passed on a small amount of energy to the former in the form of energy of translation.

Considering the fact that the distance between the lower (metastable) level to the next higher one is only 0.05 electron volts, an amount which is comparable to the average kinetic energy of thermal agitation, it may be expected that neon atoms can in this case pass on energy of translation to metastable atoms and bring them into a state from which they can return to the lowest level by radiation. Dorgelo actually found that in neon gas at 200° C the concentration of metastable atoms is much lower than at room temperature under otherwise similar conditions. It is possible, as in the cases of sodium and mercury, to influence the absorption and resonance phenomena by adding foreign gases. If hydrogen gas is added to the neon in the bulb of fig. 6 through a hot palladium tube, the resonance light disappears almost completely. Considering the fact that the energy necessary to dissociate a hydrogen molecule is 4.4 electron volts, it may be assumed that in the case in question the energy of the metastable atoms is used up in dissociation of the hydrogen.

We have considered the composite resonance phenomena in neon and mercury vapour in some detail, because later on in the discussion of the phosphorescent substances we shall encounter situations which will remind us very much of the phenomena in monatomic gases. As a transition to the fluorescence phenomena in liquids and solid substances we shall first discuss the fluorescence of diatomic molecules and of simple groups of atoms in the gaseous state.

## Fluorescence of iodine vapour

Iodine vapour ($I_2$) is a typical example of a diatomic gas. The fluorescence of this gas was also investigated by Wood and others. Since the spectrum of a molecular gas (band spectrum) is much richer in lines than the line spectra of the monatomic gases, we must expect a much more complicated scheme of energy levels in the case of a molecule. With a molecule, just as with an atom, an electron can move in orbits of higher energy, and the position of the energy levels here also is mainly determined by these orbits. Instead of one level, however, in the case of a molecule a given electron orbit is responsible for a series of approximately equidistant levels which are due to the different vibration states of the two atoms with respect to each other. Moreover, each vibration level is found to be made up of a number of levels due to the different possible values which may be assumed by the rotation energy of the molecule.

In iodine vapour at room temperature all the molecules are in the lowest state, and, moreover, in the lowest vibration level of that state, since thermal agitation is not sufficient to excite higher vibration states. The molecules, however, will rotate due to thermal agitation, so that not only the lowest, but also higher rotation states will be represented. For all these rotation states transition to a higher electron state is possible by absorption of light of a suitable wave length. The maximum of these transitions lies at 2.25 electron volts, i.e. in the green; this results in the violet colour of iodine vapour by transmitted light. Wood irradiated iodine vapour with light of the green mercury line 5461 Å. This line practically coincides with an absorption line which indicates a transition from the 33rd rotation state of the lowest vibration state of the lowest electron energy level to the 34th rotation state of the 26th vibration state of the higher electron energy level. From this state the molecule can upon radiation not only return to the lowest but also to the 1st, 2nd etc. vibration states of the lowest electron level. According to a rule of spectroscopy which only permits a jump of one in the rotation quantum number in a transition, the molecule can only pass over to the 33rd or the 35th rotation state of these vibration states. The result is that a number of double lines are observed in the fluorescence light which follow each other in the spectrum at approximately equal distances, and all of which have a wave length greater than 5461 Å. In all, 27 such doublets are observed.

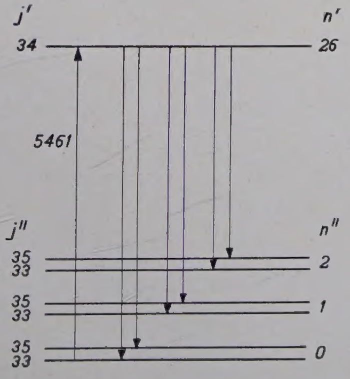


Fig. 8. Energy level diagram (partial) of an iodine molecule.
n'n'' vibration quantum numbers
j'j'' rotation quantum numbers.

In *fig. 8* we have reproduced the scheme of energy levels for iodine with the transitions in question, and in *fig. 9* the fluorescence spectrum.

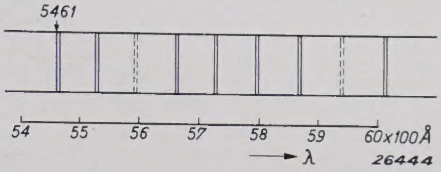


Fig. 9. Fluorescence spectrum of iodine vapour irradiated with the green mercury line 5461 Å. The marked doublets indicated by dotted lines are invisible due to selective absorption.

If a foreign gas, for instance helium, is added to the iodine vapour, an exchange of energy takes place between the excited molecule and the foreign atoms. As a result of this, excited molecules now appear in other vibration states and in rotation states other than the 34th, and the emission spectrum becomes richer in lines and resembles more nearly the normal band spectrum of iodine.

If iodine vapour is irradiated with non-monochromatic light, sunlight for example, the possibilities of absorption become more numerous, and the emission spectrum becomes richer in lines. In this case also a band spectrum is observed in fluorescence which, with respect to the wave length of maximum absorption (about 5400 Å) is displaced in the direction of longer waves. The fluorescence light of iodine vapour is indeed yellow-green in colour, while the maximum absorption lies in the green and blue-green part of the spectrum. We shall encounter this phenomenon again in the fluorescence of more complicated molecules. It is known as Stokes' law.

## Use of potential curves

On the basis of the energy level diagram alone it is impossible to obtain a complete insight into the optical phenomena of molecules, since the phenomena are partially determined by the mutual separation $r$ of the atoms in the molecule. We shall explain the use of potential curves in this connection by the example of iodine. If we consider two iodine atoms at a great distance from each other (*fig. 10*), and let them approach each other, the energy will decrease as the distance decreases until the atoms (I) have reached the distance at which they are normally bound in the molecule (2.7 Å). If we force the atoms to approach each other still more closely, they repel each other, and the mutual energy begins to increase. This energy is often conceived as a potential energy, and the curve giving this energy as a function of the distance is called a "potential curve". The potential curve of the normal iodine molecule, $I_2$, has a minimum, therefore, at 2.7 Å. The depth of the minimum (1.54 electron volts) is equal to the chemical binding energy. Besides the normal state, among others a higher energy state of the atom I is known with an energy of 0.94 electron volt. If we repeat the process with an ordinary iodine atom and an excited atom at 0.94 volt, we find, as may be seen from the analysis of the band spectrum, a curve with a minimum at 3 Å; the depth of this minimum is 0.55 electron volt.

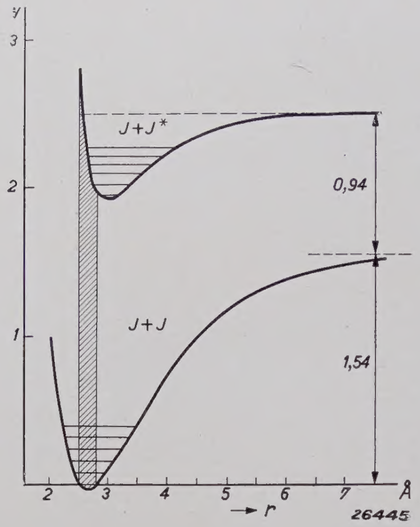


Fig. 10. Potential curves of an iodine molecule. The potential energy $V$ in electron volts counted from the level corresponding to the lowest state as a function of the mutual separation $r$ of the nuclei in Å. The vibration levels 0, 5, 10, 15, 20 and 25 are drawn.

In fig. 10 several vibration levels are also indicated, for both curves the levels with the numbers 0, 5, 10, 15, 20, 25. We count the energy of the molecule from the zero vibration state of the lowest electron level and read from the figure for instance that the 10th vibration state of the normal molecule has an energy of 0.16 volt. Moreover, the amplitude of this vibration may be deduced from the figure, since it is clear from the curve that the distance apart of the centres of the two atoms fluctuates between 2.3 and 3.2 Å. There is an important principle formulated by J. Franck and E. V. Condon which says that upon absorption of a light quantum, there is preferably a transition between states which lie directly one above the other in the potential curves of the diagram, so that it may be said that upon absorption the separation of the centres of the atoms changes as little as possible. In fig. 10 the limits of the absorption spectrum are constructed approximately by drawing vertical lines through the outermost points of the zero vibration level. One then finds (see cross hatched area) for the points of intersection with the upper curve values of 1.95 - 2.8 electron volts (6500 - 4400 Å). The last value (2.8 electron volts) lies above the energy necessary to separate two atoms and to excite one atom (1.54 + 0.94 = 2.48 electron volts). By absorption of light with a wave length shorter than 12390/2.48 = 5000 Å the molecule $I_2$ is actually dissociated into one normal and one excited atom; fluorescence is then no longer possible.

**Fluorescence of uranyl compounds**

The compounds of the radical $UO_2$, for example $UO_2(NO_3)_2$, $K_2UO_2(NO_3)_4$, form a group of solid substances to which what has been stated about gaseous compound also applies. The radical $UO_2$, which occurs in the compounds mentioned as a doubly charged positive ion, $(UO_2)^{++}$, forms such a closed unit that even in the solid state absorption and emission bands appear which are comparable to those of free molecules in the gaseous state. We shall illustrate this with the help of potential curves. The radical $UO_2$ is entirely comparable with the molecule $CO_2$, which is known to have a symmetrical extended structure (*fig. 11*). The three atomic nuclei lie in a straight line with the two oxygen atoms at the ends. It is known that such symmetrical molecules can vibrate symmetrically, the two oxygen atoms approaching and receding from each other by turns, and the central atom remaining at rest. The frequency of this vibration for $UO_2$ in the lowest state is $2.5 \times 10^{13}$ periods/sec, corresponding to a reciprocal wave length of 830 $\mathrm{cm}^{-1}$, and therefore the vibration quantum is about 0.11 electron volt. If an uranyl salt is irradiated with blue or violet light, a number of bands are found in the fluorescence spectrum whose differences in frequency correspond to an energy difference of 0.103 electron volt.

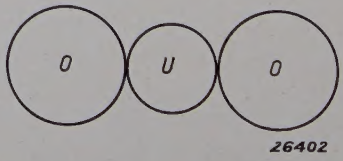


Fig. 11. Model of the symmetrical extended group of atoms $(UO_2)$.

In order to obtain a complete picture, however, the absorption spectrum must also be considered. From this it is found that the distance between the emission bands is greater (0.103 electron volt) than that between the absorption bands (0.086 electron volt). When a uranyl compound is irradiated at a low temperature (—180° C for instance), the absorption band lying farthest toward the red coincides with the emission band lying farthest toward the violet. At room temperature a weak band is added to the series of absorption bands at the red end at a distance equal to that between the emission bands (0.103 electron volt), while at the violet end of the emission spectrum a new band appears at a distance equal to that between the absorption bands (0.086 electron volt). At a higher temperature, therefore, there are three absorption and emission bands which exactly coincide (*fig. 12)*. The late N. Moerman of Eindhoven gave the following interpretation of this phenomenon (see *fig. 13*). At a low temperature (—180° C) only the lowest level is occupied, absorption is therefore only possible out of this level. The separation (0.086 electron volt) of the absorption bands is given by the spacing of the vibration levels of the excited state. It is known that the radiation takes place very slowly with uranyl (time $10^{-5}$ sec compared with $10^{-8}$ sec for sodium); this time is so long that the vibration in the excited state becomes adapted to the temperature. At —180° C therefore, in the excited state also, only the zero vibration level is represented. The emission bands due to this state exhibit the spacing 0.103 electron volt, which belongs to the various vibration levels of the lowest state. When the temperature rises, not only the first vibration level of the lowest state (absorption) but also that of the excited state (emission) plays a part.

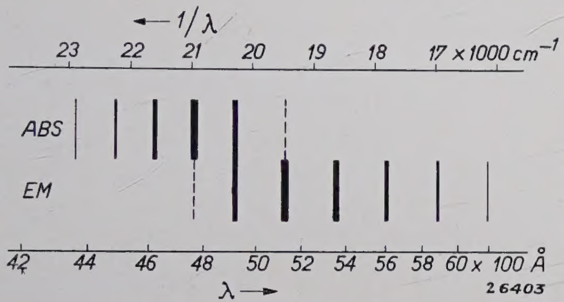


Fig. 12. Emission and absorption spectra of potassium uranyl sulphate (25° C). The lines represent diagrammatically the position and intensity of the bands. The bands indicated by broken lines disappear at very low temperatures 1000 cm$^{-1}$ = 0.1239 electron volts).

Uranium glass, which is important in the technique of discharge tubes, exhibits a fluorescence which resembles that of the uranyl salts. Here also there is a maximum of emission in the green, while the absorption extends from the blue-green to far in the ultraviolet. There is, however, only a vague band structure, which is not surprising with a glass.

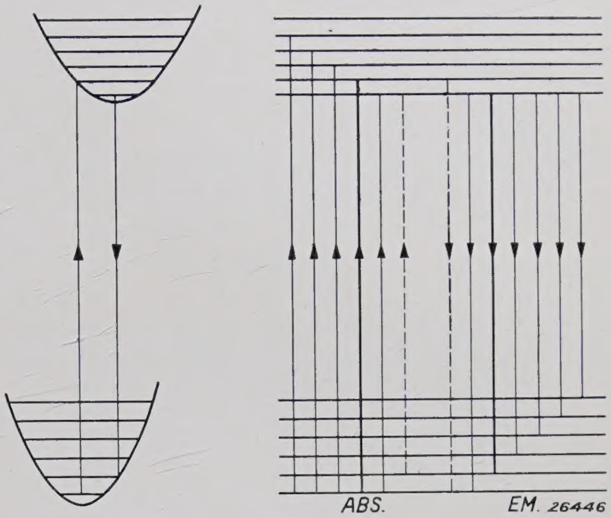


Fig. 13. Left: potential curves of the $UO_2$ radical with the strongest transitions in emission and absorption. Right: energy levels with transitions in the same order as the lines in fig. 12. The levels indicated by dotted lines do not occur at — 180° C, while they do occur at room temperature.

### Fluorescence of organic compounds

Among organic compounds there are many which fluoresce strongly in solution. Fluorescein and eosin are well known examples. Eosin, which has a beautiful rose colour by transmitted light, is distinguished by strong absorption in the green and blue parts of the spectrum; the maximum of this absorption lies at 5250 Å. If light from this part of the spectrum is allowed to fall on a solution of eosin, a greenish fluorescence light is radiated, whose spectral distribution possesses a maximum at 5450 Å. In *fig. 14* the absorption and emission spectra of such a solution are reproduced. It may be seen that Stoke's law is fulfilled. Although it is not exactly known to which group of atoms in the complicated

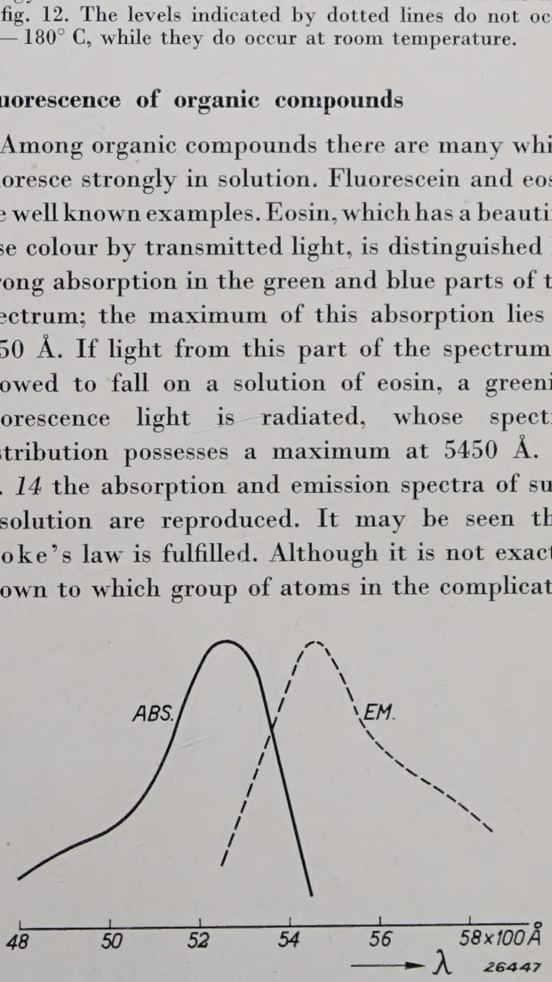


Fig. 14. Spectral distribution of the absorption and emission of eosin.

eosin molecule the fluorescence is due, and although it is impossible to indicate the correct position of the potential curves for this group of atoms, we may assume that the curves are similar to those in the cases of iodine and uranyl. The fact that the emission spectrum in this case does not consist of fine lines but of a continuous band, must be explained in the same way as in the case of uranium glass, as due to the fields of the water molecules which blur the spectrum.

The influence of concentration and of foreign substances on the efficiency of fluorescence of solutions is important. If the ratio of the radiated fluorescence light to the absorbed light is measured for a very dilute solution of fluorescein, it is found that per quantum of light used for irradiation, approximately one quantum is radiated. The efficiency is, therefore, as high as possible. If the concentration increases, the efficiency decreases. Energy must therefore be destroyed. The same thing happens when an electrolyte, KI for instance, is added to a dilute solution of fluorescein. In this case it can be proved that as a result of the irradiation free iodine is formed which darkens to a starch solution. This may be explained in the following way. The fluorescein molecule, which has attained a higher energy state by absorption of a light quantum, uses up this energy by collision with an $I^{-1}$ $(H_2O)$ ion in a chemical reaction giving free iodine:

$$I^{-1}\,(H_2O) \rightarrow I\,H + (OH)^{-1}.$$

We are therefore concerned here with a case analogous to that of the fluorescence of gases, where we saw that the energy taken up by the atom as a result of light absorption can be transformed wholly or partially into atomic energy of another form (translation, vibration, dissociation).

The decrease in efficiency by increase of concentration of the fluorescent substance may then be interpreted as follows. The molecules of the substance can easily take over energy from an excited molecule and transform it into vibration and translation. With normal absorption of light, without fluorescence, this occurs even in the absorbing molecule itself. The fluorescing substances must, therefore, be distinguished by certain groups of atoms which are "shielded" from their environment in such a way that they have time enough to emit again as radiated light the energy they have received by the absorption of light. In the case of phosphorescent substances, which will be discussed in a later article, we are concerned with even longer lifetimes of the excited states.

# TECHNICAL APPLICATIONS OF SECONDARY EMISSIONS

by J. L. H. JONKER and M. C. TEVES.

537.533.8 : 621.385.15 : 621.385.833

Several types of valves are described in which the electron current is amplified by secondary emission: the dynatron, electron multipliers and hot cathode amplifier valves.

The phenomenon of secondary emission, which was described in detail in a previous number of this periodical¹), was discovered about 35 years ago. Since its discovery means have been sought of controlling the phenomenon. In cases where it arises spontaneously in electron tubes and is undesired, attempts are made to avoid it or at least to nullify its effect. On the other hand attempts have been made to design tubes in which this new source of electrons should be technically useful. Some of the tubes which have found a certain degree of technical application will be treated in this article.

## The dynatron

The first technical application of secondary electron emission was indicated by Hull in 1915. He designed a valve, called a dynatron, in which secondary emission was used to obtain a negative resistance. The action of this valve is as follows (*fig. 1*). Part of the electrons leaving the cathode $k$ arrive on the positive electrode $a$, while part of them pass through the opening of this pierced electrode and reach the secondary emitting plate $p$, which is also at a positive potential but lower than $a$. The secondary electrons freed from the plate are captured by the electrode $a$. If $I_{\text{prim}}$ is the primary current to the plate, $\delta$ the coefficient of secondary emission, then the total current to the plate is

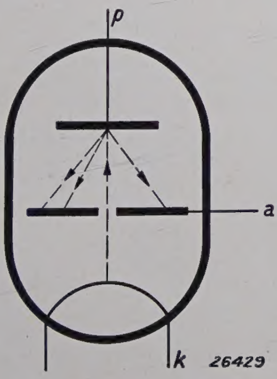


Fig. 1. Diagram of the dynatron.

$$I_p = I_{\text{prim}} (1 - \delta).$$

Since the coefficient $\delta$ may be considerably greater than one (for instance 5), the current to the plate will in many cases become negative.

*Fig. 2* gives an illustration of the current $I_p$ as a function of the voltage $V_p$ of the plate. The voltage of the electrode $a$ is here kept constant at $V_a = 180$ volts. At low values of $V_p$ only a few secondary electrons are formed per primary electron. The coefficient of secondary emission increases, however, with the voltage, and becomes greater than unity when $V_p > 20$ volts. At higher voltages than this, therefore, the plate current is negative. With increasing voltage the plate current becomes steadily more negative, due to the increase in $\delta$. In this region, therefore, the valve has a negative resistance, i.e., $\mathrm{d}V_p/\mathrm{d}I_p < 0$. When, however, $V_p$ becomes greater than $V_a$, the current of secondary electrons begins suddenly to decrease, since now the electrons must run counter to a potential difference in order to leave the plate. The plate current consequently increases strongly, and for $V_p = 250$ volts it is practically equal to the primary current.

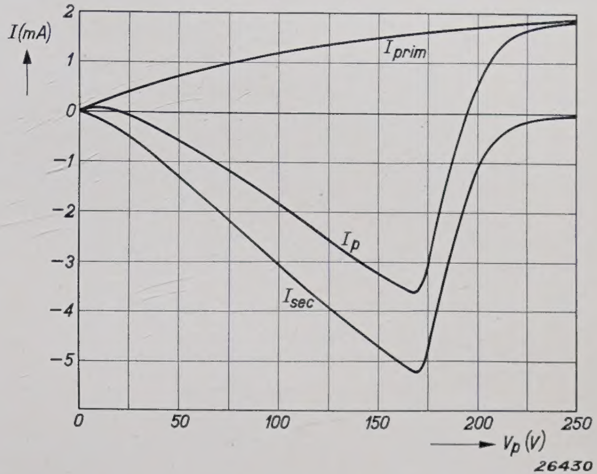


Fig. 2. Variation of primary ($I_{\text{prim}}$), secondary ($I_{\text{sec}}$) and resultant ($I_p$) electron currents to the plate as functions of the plate voltage $V_p$ at constant anode voltage $V_a$.

The most important property of the dynatron is that, because of its negative resistance, it offers a simple method of exciting electrical oscillations. If there is a negative resistance in parallel with an oscillating circuit, and if this resistance is smaller in absolute value than the positive equivalent resistance of the circuit itself, the damping of the

---

¹) H. Bruining, Philips techn. Rev. **3**, 80, 1938.

combination becomes negative; that is, an oscillation excited in the circuit continues to increase in amplitude. Actually this increase is limited because the internal resistance of the dynatron is only negative in a limited voltage interval. If the oscillation takes place in the linear portion of the descending characteristic, and, therefore, at not all too great an amplitude, a practically sinusoidal oscillation can be generated.

Oscillations of very high frequencies can be excited by means of the dynatron. This shows that secondary emission is a phenomenon which takes place very rapidly. An observable lag between the incidence of the primary electron and the emission of secondary electrons does not appear under normal conditions; the difference in time is certainly shorter than the transition time of the secondary electrons from the plate to the pierced electrode, which time is usually less than $10^{-8}$ sec.

The most obvious advantage of the dynatron over the familiar oscillator valve is the absence of a reaction coil.

For high powers with high working voltages the dynatron is less suitable as a generator, since the coefficient $\delta$ decreases again at high voltages.

## Electron multipliers

One primary electron may, as we have seen, free a number of secondary electrons. Use is made of this multiplication in the electron multiplier for amplifying a current. A very high amplification can be attained in this way by employing secondary emission several times successively. A primary electron current, emitted by an illuminated *photo-cathode*, is focussed by means of suitably chosen electric fields or by a favourable combination of electric and magnetic fields, on an electrode which has a surface with a high capacity for secondary emission. The secondary electrons from this electrode, which are already a multiple of the primary electrons, are focussed in the same way on a following electrode where multiplication again takes place. This process may in principle be repeated any number of times; the limit is practically given finally by the permissible load on the last electrode or the final anode of the system, or by possible space charges.

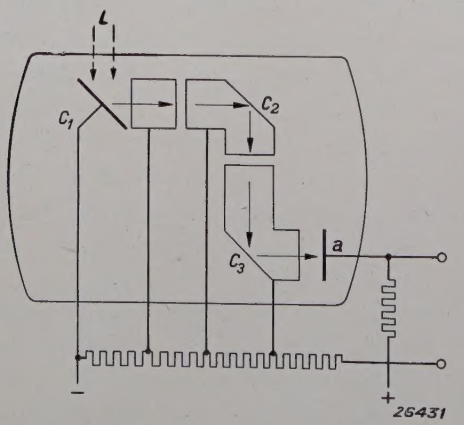


Fig. 3. *L*-electron multiplier, $c_1$ photo-cathode, $c_2$, $c_3$ secondary cathodes and *a* final anode.
The cylindrical tubes serve as focussing electron lenses, the arrows indicate approximately the path of the electrons.

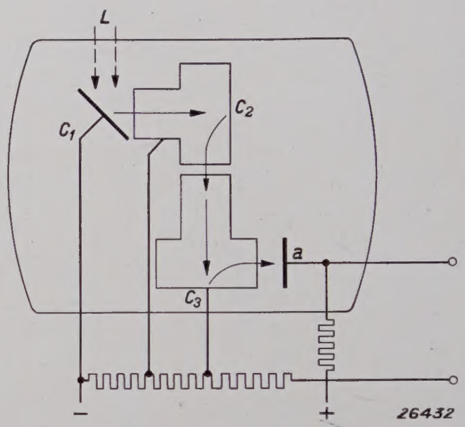


Fig. 4. *T*-electron multiplier. Explanation as in fig. 3.

There are various possible ways in which the electrons in a multiplier may be directed to the succeeding secondary emitting surface in each case. Zworykin has worked out several models, in which only electric fields are used (*figs. 3* and *4*). Only a few successive steps can be applied, however, because of difficulties in keeping the beam of electrons concentrated. The voltages of the successive electrodes are taken from a common potentiometer.

The tube constructed by Weiss uses also only electric fields. In this tube a number of wire gauzes with a high secondary emission (*fig. 5*) are connected in series with from left to right successively higher positive potentials. The electrons which strike a wire of the gauze free secondary electrons which are attracted to a following gauze, etc. The electrons which pass through a mesh are not multi-

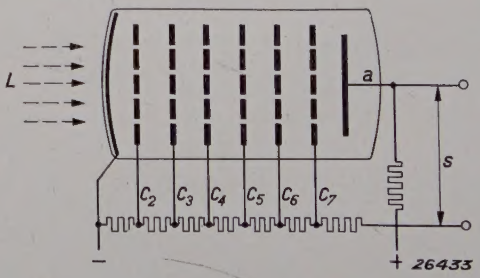


Fig. 5. Wire-gauze electron multiplier with transparent photo-cathode, $c_2$ ... $c_7$ wire gauzes which serve as secondary cathodes, *a* final anode.

plied, and the amplification is, therefore, relatively low. In addition a transparent photocathode is used here and the light is incident from one side while the electrons are emitted from the other.

The most satisfactory construction, and one which permits a large number of amplification stages, is one in which the electrons are focussed on the successive secondary cathodes by a transverse magnetic field (*fig. 6*). The primary and all the secondary cathodes ($c_1$, $c_2$ ...) are here mounted in a straight line in one plane. In a second plane, parallel to the first there is an equal number of anodes ($a_1$, $a_2$ ...). Each cathode is connected to the foregoing anode so that upon application of the voltage the field on the cathodes is sufficiently high to remove the electrons from it. The transverse magnetic field $H$ of adequate intensity causes the accelerated electrons to describe almost semicircular paths. The electric and magnetic fields are so adjusted relative to each other that the electrons just reach the following cathode. The secondary electrons freed there, a multiple of the incident electrons, are directed upon the following cathode in the same way, and so on.

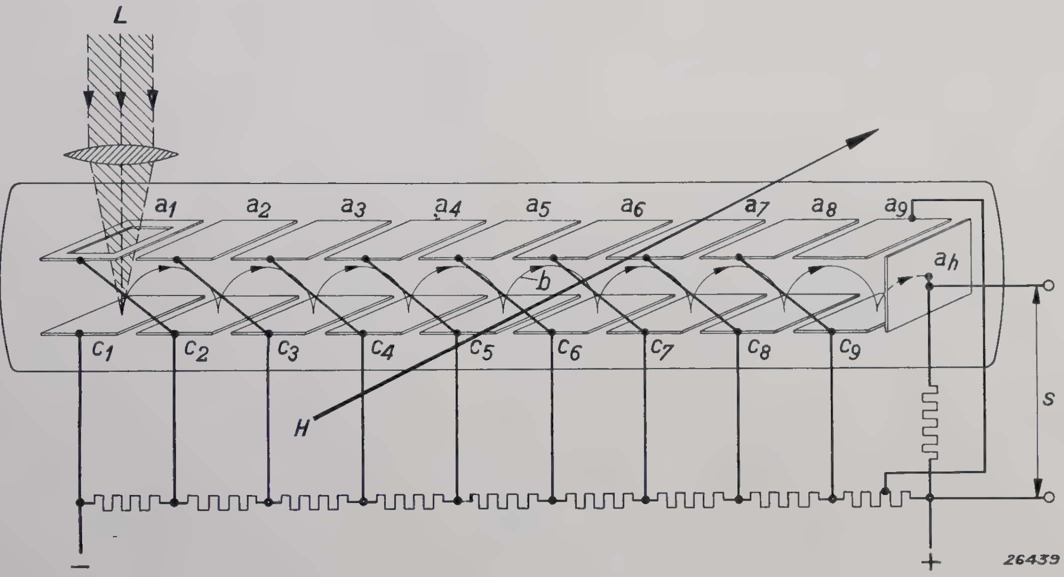


Fig. 6. Electron multiplier with magnetic focussing.
$c_1$ photo-cathode, $c_2$, $c_3$ ... secondary cathodes, $a_1$, $a_2$ ... auxiliary anodes and $a_n$ final anode
→ direction of the transverse magnetic field $H$.

The magnetic field must be carefully adapted to the accelerating electric field between the electrodes, for instance by regulation of the excitation current of the magnet. Moreover, the magnetic field must be homogeneous over the whole length of the electrode system, and it must be accurately directed, that is perpendicularly to the longitudinal axis of the system and parallel with the cathode and anode planes (see fig. 6). When these conditions are satisfied, tubes with ten or more successive stages may be constructed. With a voltage of 200 volts between the successive cathodes and their corresponding anodes, and when caesium oxide is used as secondary emitting surface, an amplification of the current by a factor of 5 per stage is easily attained. For a multiplier of this type with 10 stages this means an amplification of $5^{10}$ or about 10 million.

In a multiplier there is not only a photo-cathode but also secondary emitting cathodes. If different kinds of surfaces were used for these cathodes, there would be a danger that they might have undesirable effects upon each other during preparation. It is, therefore, advantageous to use the same kind of surface for both purposes. At first sight it seems difficult to find a suitable surface, since quite different requirements are made of a surface which is to have a high secondary emission from those made of a surface which must have a high photosensitivity. There is, however, such a surface, and it is used in the multipliers here described. A layer of silver is covered with caesium oxide and adsorbed caesium. The photo-sensitivity of this cathode is due to the adsorbed caesium atoms which can easily be ionized by light. The capacity for emitting secondary electrons is due to the caesium oxide; the adsorbed caesium atoms are, therefore, not essential for the secondary emission. It has been found that this cathode has a higher secondary without a covering of caesium atoms than with such a covering. With the covering of caesium atoms the photo-sensitivity is at a maximum.

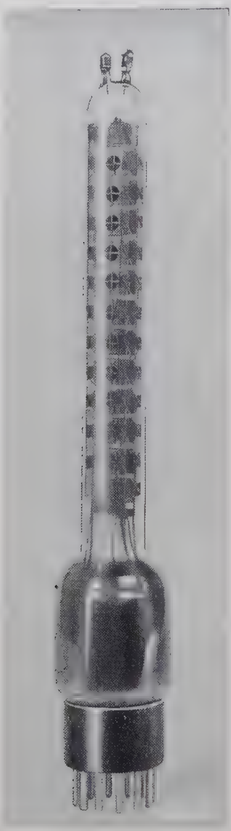


Fig. 7. Electron multiplier type 4698, constructed according to the scheme of fig. 6 with eleven stages.

The great advantage of electron multipliers is that they can amplify very rapid current variations without deformation, as long as the variations do not occur in a shorter time than $10^{-8}$ sec. The resistance and self-induction of the leads and the capacity between the electrodes have practically no influence on the multiplication factor, even at high frequencies. The current at the final anode exhibits a time difference with respect to the photo-current which is independent of frequency, but this gives practically no difficulties.

The electron multiplier is, therefore, an ideal amplifier for photocurrents of all frequencies, and even for direct current. However, because of the complications inherent in the use of such a tube the application is restricted to the region of very small amounts of light, as in television with mechanical scanning [2], astronomical measurements, spectrophotometers, etc. where we are concerned with photoelectric currents of the order of magnitude of from $10^{-14}$ to $10^{-16}$ A. In such cases with normal amplification by means of amplifier valves the noise due to the first coupling resistance (thermal motion of the electrons) and to the relatively high cathode current in the first amplifier valve (shot effect) is predominant [2, 3]. These noises are of course present even without a photo-current. In the multiplier practically the only interference is the inevitable shot effect of the photo-current itself, and this is proportional to the square root of the photo-current.

The use of the multiplier offers no advantage when the photo-current becomes greater than about $10^{-8}$ A (for constant illumination) or about $10^{-7}$ A (for flickering light, of audio-frequency for instance). At currents higher than these values it is simpler to use ordinary amplifiers.

*Fig. 7* is a photograph of an electron multiplier with eleven stages of amplification by secondary emission (type 4698).

## Secondary emission in amplifier valves with hot cathodes

Just as with the current in a photocell, attempts have been made to amplify the electron current in an amplifier valve by means of secondary emission.

The realisation of this concept, shown diagrammatically in *fig. 8*, was prevented until recently by practical difficulties. If a hot cathode and a surface which in itself has a high and satisfactorily constant secondary emission are both included in one bulb, the properties of the secondary emitting surface may be adversely affected by the substances evaporated from the cathode (barium, barium oxide) and condensed on the secondary emitting surface. This alteration in the surface will as a rule mean a decrease of the secondary emission, and will have an unfavourable influence on the amplification of the valve.

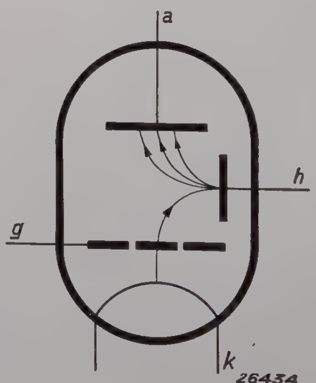


Fig. 8. Diagram of an amplifier valve with a hot cathode and an auxiliary cathode for amplification by secondary emission.

---

[2] H. Rinia and C. Dorsman, Television system with Nipkow disc. Philips techn. Rev. **2**, 72, 1937.

[3] M. Ziegler, Noise in amplifiers contributed by the valves, Philips techn. Rev. **2**, 329, 1937.

In the electron multipliers described above it was possible in the way there described to overcome a similar difficulty by the use of a material which is suitable not only for photoelectric but also for secondary emission. The idea of covering the hot cathode and the plate with the same kind of surface would occur here also, but a material suitable for both purposes has not been found. Another solution had to be sought.

This solution was based on the fact that molecules evaporating from a surface in a high vacuum move in practically straight lines, so that they will not strike the secondary emitter if the latter is "out of sight" of the hot cathode. The primary electrons emitted from the cathode must then be conducted to the secondary emitting plate by a roundabout way. This can be done by means of electric and magnetic fields in a way analogous to that discussed under the various systems of electron multipliers.

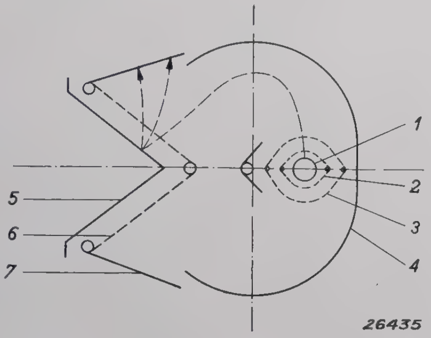


Fig. 9. Cross section of amplifier valve type 4696. *1* cathode, *2* control grid, *3* screen grid, *4* screen at cathode potential, *5* auxiliary cathode, *6* anode grid and *7* anode.

For amplifier valves the use of an external magnetic field is not so simple, and the adjustment of that field is very critical. Electrostatic deflection is in this case greatly to be preferred to magnetic deflection. Electrostatic deflection is possible for example by repulsion by an electrode at a low potential or by attraction by an electrode at a high potential. This electrode may, when its shape is suitably chosen, also bring about a concentration of the electron beam.

The interior of an amplifier valve with one stage of secondary emission, type 4696, is shown in the two accompanying figures. *Fig. 9* shows a cross section of the system of electrodes; *1* is the cathode, *2* the control grid and *3* the screen grid. The electrons pass through the screen grid *3* and are as it were reflected by the curved screen *4* and concentrated on the auxiliary cathode *5*. The surface of the latter has a high secondary emission and is at such a potential (150 volts) that a good factor, $\delta = 5$, for secondary emission is obtained. The secondary electrons are attracted away from the cathode by the grid *6*, which is at anode potential (250 volts), and move toward the anode *7*. *Fig. 10* is a photograph of the construction with the screen cut away to show the interior. To the right may be seen the cathode with the surrounding grids, to the left the auxilary cathode, the anode grid and the anode plate. Finally *fig. 11* shows the curvature of the equipotential planes in a valve constructed as described above. This diagram was recorded with an enlarged model in an electrolytic trough [4]). Between screen grid and auxiliary cathode the electrons pass through two concentrated potential fields, while a kind of reflection takes place at

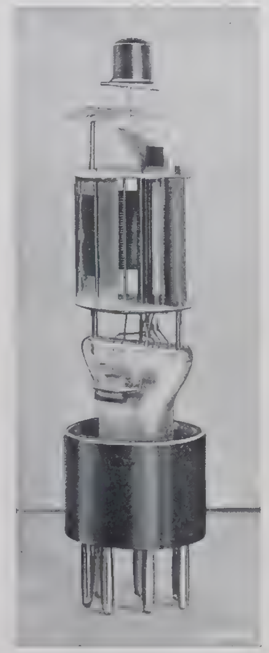


Fig. 10. Photograph of the interior of valve type 4696.

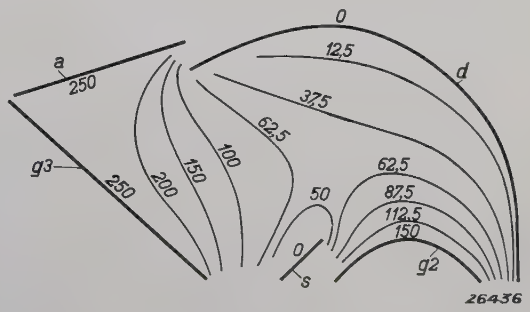


Fig. 11. Curvature of equipotential planes in valve 4696.

---

[4]) In this method an enlarged model of the construction to be investigated is placed in a container filled with an electrolyte. When the electrodes are given the required potentials current flows between them, and the potential can be measured at each point with the aid of a probe electrode.

the region of low potential caused by the curved screens.

Since in this amplifier valve one is concerned with currents of a few milliamperes, considerable space charges may appear, which would not only deform the field in the neighbourhood of the screen, but also at the surface of the auxiliary cathode, and thereby prevent part of the secondary electrons from reaching the anode. This is avoided by the introduction of the grid *6* at anode potential directly in front of the auxiliary cathode *5*. If this measure is not taken the anode current becomes quite closely dependent on the anode voltage, in other words, the internal differential resistance of the valve falls, which is undesirable for amplification purposes.

The great advantage of this secondary emission valve lies in the fact that, not only the anode current, but also the slope $\mathrm{d}I_a/\mathrm{d}V_g$ is increased by about a factor of 5 as a result of amplification by secondary emission. Particularly when the external anode impedance may only be very low, as in the amplification of wide frequency bands (television), this steepness of slope is very welcome.

If two valves are compared, one with and one without amplification by secondary emission, it is found that with the same anode current the slope of a valve with secondary emission is considerably greater. For example in *fig. 12* let the variation of $I_k$ be given as a function of the grid voltage $V_g$. At a given grid voltage $OC$ without amplification by secondary emission the cathode current $I_k$ as well as the anode current $I_a$ is equal to $OB$. If an auxiliary cathode for secondary emission is now introduced, then, when $I_a$ is kept constant, the current $I_k$ will become smaller, since $I_a = \delta \cdot I_k$. $\delta$ is here the ratio of the electron current emitted from to that incident on the auxiliary cathode. A factor $\delta = 5$ can be attained with the difference of potential of 150 volts between cathode and auxiliary cathode, so that the necessary current $V_k$ falls to about $^1/_5$ of its former value ($OB'$ in fig. 12). At the point $A'$ on the characteristic $I_k = f\,(V_g)$, the slope $\mathrm{d}I_k/\mathrm{d}V_g$ is, however, greater than $^1/_5$ of that at point $A$; the slope of the valve with secondary emission, $\mathrm{d}I_a/\mathrm{d}V_g = \delta \cdot \mathrm{d}I_k/\mathrm{d}V_g$, is therefore greater. The following calculation will make this clearer.

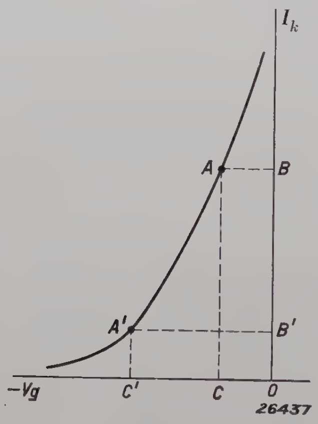


Fig. 12. Cathode current $I_k$ as a function of the grid voltage $V_g$.

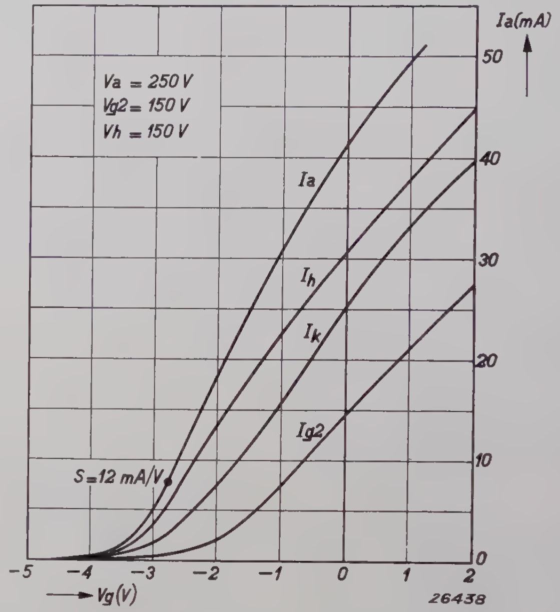


Fig. 13. Currents to the various electrodes of valve type 4696 as functions of the grid voltage $V_g$. $I_a$ is the anode current, $I_k$ is the cathode current, $I_h$ is the current to the auxiliary cathode, $I_{g_2}$ is the current to the screen grid.

For the cathode current $I_k$ the following formula holds:

$$I_k = A\;(V_g + b)^K,$$

$A$ and $b$ are determined by the construction and the anode potential $V_a$. Without secondary emission the slope is:

$$\frac{\mathrm{d}I_k}{\mathrm{d}V_g} = A\,K\,(V_g + b)^{K-1} = A^{\frac{1}{K}}\;K I_k^{\frac{K-1}{K}}.$$

With secondary emission:

$$\frac{\mathrm{d}I_a}{\mathrm{d}V_g} = \delta^{\frac{1}{K}}\,A^{\frac{1}{K}}\;K\;I_a^{\frac{K-1}{K}}$$

For *the same* anode current, therefore, the slope is greater in the second case by a factor $\delta^{1/K}$. Since $K$ is 1.6 for not too small currents, one finds for $\delta = 5$ that the slope has become $5^{0.6} = 2.6$ times greater.

Finally *fig. 13* gives the currents to the various electrodes of a valve of the above-described construction as functions of the voltage of the control grid. With this valve one stage of amplification by secondary emission has been employed and a slope of from 12 to 14 mA/V has been reached at an anode current of 8 mA, with a cathode current of only 2.5 mA, of which about 2 mA go to the auxiliary cathode 5, and 0.5 mA to the screen grid (fig. 9). In principle is is possible to employ more stages, when the construction of course becomes more complicated and the required voltage $V_a$ higher. For these reasons only one stage has been used in this amplifier valve.

---

# AUDITORIUM ACOUSTICS AND INTELLIGIBILITY

by R. VERMEULEN.

534.843.5

The phenomena which influence the intelligibility of speech in an auditorium are discussed. Starting from knowledge gained by experience about intelligibility as a function of the intensity of the signal and of the noise, it is shown that in a large room with much reverberation the spoken word is only intelligible at certain places. Details are given of the contribution to intelligibility by the direct and the reflected sound. From the assumption that only those waves which reach the listener within 1/15 of a second after the direct sound contribute effectively to the intelligibility, are derived the principles for the design of an auditorium with good acoustics.

An architect who is designing a theatre auditorium will not fail to provide an unhindered view of the stage from every seat. There is, however, some doubt whether he always makes as good a provision for the intelligibility of the spoken word, which is certainly equally important in the enjoyment of a play. It is not sufficient simply to provide for the proper reverberation time in an auditorium, the significance of which was explained in a previous article [1]), because the intelligibility, especially of the spoken word, is determined also by other factors. Although the reverberation time is the same at all points in the hall as required by Sabine's law, nevertheless it may be more difficult to follow speech at one point than at another, more favourable position. It is mainly due to the great importance of intelligibility of speech for the development of telephone communication, that many experiments have been carried out in the last few decades on the dependence of intelligibility on all kinds of disturbing and deforming effects [2]).

### Factors of influence on intelligibility

It will only be possible here to give several results. In the first place intelligibility is to a high degree dependent on intensity. In order to express this fact in figures it must be possible to measure intelligibility. This can be done by having a large number of sentences, words or sylables spoken and finding out what percentage is understood correctly. If syllables with no relation or meaning are used (nonsense syllables), the percentage correctly understood, which we shall call "intelligibility", will of course be much smaller than when a connected sentence is spoken, since in the latter case the words which are less well heard will be automatically supplied. The relation between this "comprehensibility" and "intelligibility" is shown in *fig. 1*.

If the intelligibility is determined at different sound intensities of the speech, without the listener being disturbed by reverberation and foreign sounds, the ratio given in *fig. 2* at 0 is obtained. The other

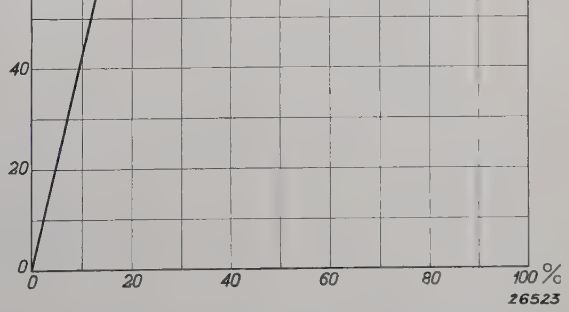


Fig. 1. Abscissa: intelligibility of nonsense syllables, ordinate: percentage of simple questions answered correctly. This curve shows that an intelligibility of 50% is enough to make it possible to follow an argument.

---

[1]) A. Th. van Urk, Auditorium acoustics and Reverberation, Philips techn. Rev. **3**, 65, 1938.

[2]) Good summaries may be found in the following books: Harvey Fletcher, Speech and Hearing: F. Trendelenburg. Klänge und Geräusche.

curves in this figure refer to cases where the listener is disturbed by noise of different intensity. While the nature of the noise is not immaterial, the character of the curve remains practically unaltered. Considering that the curves are practically parallel, the conclusion may be drawn that the influence of noise corresponds to a decrease in the intensity level of the speech, or in the other words, to an increase of the threshold of the ear. It may be seen from the figure that intelligibility at equal intensities of noise and speech is about 50 per cent, which may be considered sufficient for following an argument, although an intelligibility of 70 per cent must be required for good acoustics (see fig. 1).

A second factor which may affect intelligibility, and which is especially important when amplifier installations with microphones and loudspeakers are to be used for transmission or amplification, is the change in the distribution of sound energy over the various frequency ranges. Although the fundamental tones of the voice lie in the neighbourhood of 125 cycles/sec (male) to 250 cycles/sec (female), the range from 1000 to 2000 cycles/sec is the most important from the standpoint of intelligibility. This follows from experiments whose results are given in *fig. 3*. In this figure intelligibility is plotted as a function of the limiting frequency of a filter which only passes those tones of the voice which lie below ($L$ = low), or above ($H$ = high) that limiting frequency. The inscription under the figure gives further details. It may be concluded from the figure that an intelligibility of 60 per cent can be obtained even though all the tones below 1300 cycles/sec are missing from the speech. That the quality of the spoken word is thereby very much altered, is obvious.

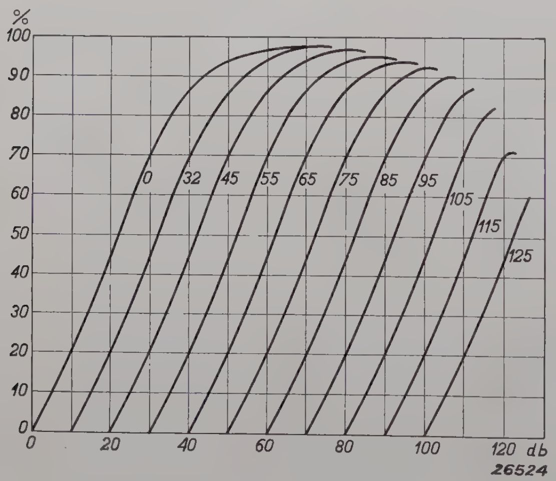


Fig. 2. The percentage of nonsense syllables plotted as a function of the level of the spoken word above that of the threshold value and that of the noise. The successive curves were recorded in each case with an increase in noise such that the threshold value increased by 10 decibels. It may be seen that the curves are practically parallel and that the threshold value lies constantly 25 decibels below the level of the noise when the latter is not greater than 40 decibels.

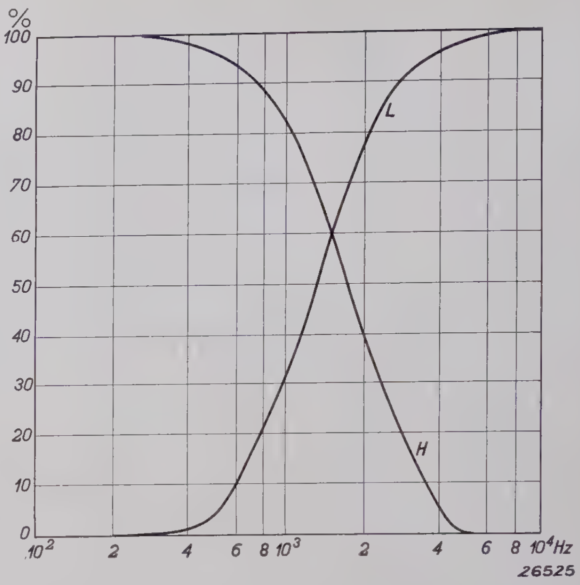


Fig. 3. The percentage of nonsense syllables understood correctly by the listener plotted as a function of the limiting frequency of a filter included in the circuit of the sound producer. Curve $L$ was determined with a filter which passes the tones below the limiting frequency so that the influence of the lack of higher frequencies is shown here. In the absence of frequencies above 2000 cycles/sec, 75% of the syllables were still correctly understood. Curve $H$ is determined with a filter passing the high frequencies: from this curve it may be deduced that when all tones below 1000 cycles/sec are lacking the intelligibility is still above 80%.

### Reverberation as a disturbing factor

Noise which decreases the intelligibility of the spoken word does not consist only of that caused by the audience, and such other sounds as the hum of fans and street noises, etc. In addition, the sound of previously spoken words which remains in the auditorium as reverberation disturbs the listener as he tries to understand the new words.

Even if it is possible, by increasing the strength of the voice, and, to a greater degree, by the use of sound amplifying apparatus, to raise the level of the spoken word sufficiently above that of the intruding noise, these methods fail when we are concerned with the reverberation of that spoken word itself: the intensity of the disturbing reverberation will increase in proportion to the direct sound. The result is that a speaker in a hall with bad reverberation can only make himself understood over a limited area of surface which cannot be increased by the use of loudspeakers.

Without going into too much detail a rough calculation will demonstrate this fact. When a number of sources of sound with a total power $W$ are set up in a hall whose walls have an absorption equivalent to an open window of area $A$, the average energy density of the reverberation is:

$$E_m = \frac{4W}{cA}, \quad \ldots \ldots \quad (1)$$

where $c$ is the speed of propagation of sound (van Urk, loc.cit.). The density of energy of the direct sound from the source indicated by the subscript $i$, at a distance $r_i$ from the source,

$$E_d = \frac{W_i}{4\,\pi\,r_i^2\,c} \quad \ldots \ldots \quad (2)$$

From these two formulae it follows that only over a limited distance will the intensity of the direct sound be greater than that of the disturbing reverberation as was found necessary for reasonably good intelligibility (50 per cent). This maximum distance is given by

$$r_i^2 = \frac{W_i}{W} \cdot \frac{A}{16\pi} \quad \ldots \ldots \quad (3)$$

If, to choose the most favourable situation, it is assumed that each source of sound is open to listeners on all sides, the area where the sound is intelligible is then:

$$\sigma = \pi \Sigma r_i^2 = \frac{\Sigma W_i}{W} \frac{A}{16} = \frac{A}{16} \quad \cdot \cdot \quad (4)$$

Equation (4) may be used to describe the situation in large rooms with much reverberation where only a small part of the space is occupied by an audience. It would for instance be possible to calculate by means of this equation, over how large a part of an indoor swimming pool the results of a competition could be announced at the same moment.

If, however, the audience occupies a large part of the area, the intelligibility area can be increased by making use of the fact that the absorption coefficient of the audience is nearly 100 per cent. This obviously completely nullifies the basis of Sabine's reverberation theory. The sound which reaches the audience directly will not be reflected and will not contribute to reverberation. The rest of the sound will give rise to reverberation whose average energy density is given by equation (1). If $p$ is the part of the sound which reaches the audience directly, the total power of the sources of sound which contribute to reverberation is $W(1-p)$, and equation (1) must now be replaced by

$$E_m = \frac{4W}{cA}(1-p) \quad \ldots \ldots \quad (1a)$$

The area which can be reached with intelligibility thereby becomes greater:

$$\sigma = \frac{A}{16\,(1-p)} \quad \ldots \ldots \quad (4a)$$

This result is important chiefly in the case when loudspeakers are used as sources of sound. In order to make $p$ as great as possible loudspeakers with directional effect may be used, and they may be directed toward the audience. In this way, even under unfavourable circumstances, an adequate intelligibility can be reached over the whole area occupied.

## Influence of the growth of sound

The above considerations are based on the assumption that only the direct sound contributes to intelligibility, and that all the reflected sound must be considered as noise. This assumption will approach the actual situation in very large closed spaces; it does not, however, give a correct picture of the acoustic relations in a smaller room.

The truth of this will be seen when the intelligibility in a room is compared with that which can be attained out of doors. The direct sound is equally intense in both cases, but indoors reverberation is present as a disturbing factor. One might therefore expect that the voice of a speaker in a hall would only be intelligible over a shorter distance than out of doors.

Experience, however, shows that the opposite is true. Although at the rear of a hall one direct sound often supplies only a very small part of the total intensity, a speaker can usually be understood much farther away in a closed room than out of doors. It is therefore apparent that sound reflected by the walls and ceiling is, at least partially, intelligible, and is not experienced as noise. The size of this part will depend upon the way in which the sound grows at the beginning of each new sound.

It will be a surprise to many to learn that when a constant source of sound is turned on the sound intensity grows in a way analogous to the way in which it dies out after the source has been interrupted. This is surprising, because while the echoing of a voice in a large church is a common experience, one can not recall having observed a gradual growth. A concise, although not entirely correct representation of this difference in the observation of reverberation and growth, is obtained by assuming that the sound impression is proportional to the logarithm of the intensity, which comes down to this, that the ear judges equal percentages of change in intensity as equal differences.

In *fig. 4b* the growth and decay of sound in a room is shown diagrammatically, with a linear scale of intensity for the variation of power radiated according to fig. 4*a*. The intensity $I_g$ during growth

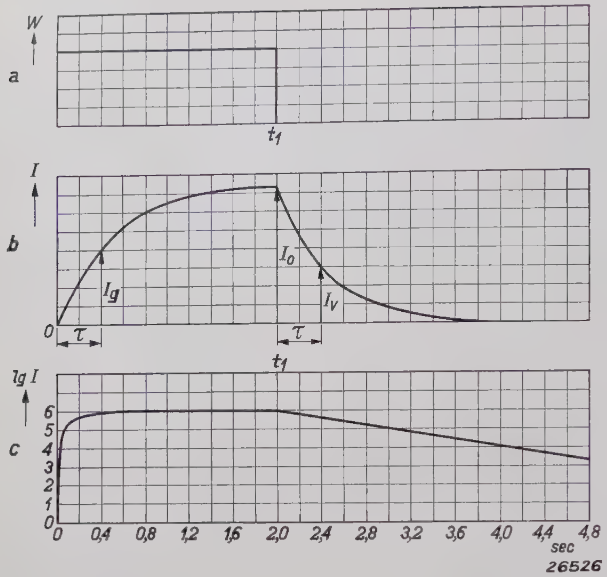


Fig. 4. Diagrammatic representation of the growth and decay of sound when a source of constant strength is switched on at $t = 0$ and stopped at $t = t_1$. a) Radiated power of the source as a function of the time. b) Intensity in the room as a function of time. The growth is the complement of the reverberation (the decay), i.e. $I_g + I_v = I_0$. c) Logarithm of the intensity as a function of time. The last curve represents approximately the subjective impression, and shows that growth seems to be of shorter duration than reverberation.

is here described as a function of the time by

$$I_g = I_0\,(1 - e^{-at}),$$

while the decay takes place according to the formula

$$I_v = I_0\; e^{-a(t-t_1)}$$

(see van Urk, loc.cit.). The growth and reverberation are complementary, i.e., the intensities $I_g$ and $I_v$ measured at the same time $\tau$ after switching on and off respectively satisfy the relation $I_g + I_v = I_0$, which is understandable when one considers the interruption of the source as the addition of a second equally intense source with a negative sign.

If the same variation is now drawn on a logarithmic scale of intensity (fig. 4*c*), the difference between growth and reverberation is clearly seen: growth takes place suddenly and is completed in a fairly short time, reverberation proceeds slowly and uniformly. Long after the intensity (fig. 4*b*) could no longer be drawn, the reverberation is still above the threshold value.

It is not easy to represent in numbers the influence of growth on intelligibility because it is quite different for different sounds. By speaking slowly the vowels can be so much drawn out that they always have the opportunity of growing to sufficient intensity. Since during that time the reverberation of the previous sound has completely disappeared, the speaker will always be able to reproduce the vowels without disturbance and with sufficient intensity. This is the basis of the preaching tone usual in churches.

The consonants, and especially b, p, d, t, g, k, etc. cannot be drawn out by speaking slowly. They cannot, therefore, on the one hand reach their full development, and, on the other hand, they suffer interference from the previous sounds. For these letters, therefore, a gradual growth of sound is permissible only to a much smaller degree than for the vowels.

In order to find out to what degree reflections from the walls may produce an increase in intelligibility even for such short sounds, an approximation of growth by an exponential curve is not sufficient. Actually the intensity varies by jumps which are connected with the arrival of the waves reflected by the various walls, and this variation will differ essentially for example at the back of an auditorium from that in the neighbourhood of the speaker.

In order to make this clear, in *fig.* 5 the propagation of a sound wave is followed step by step in an imaginary room. The 15 diagrams represent successive instantaneous states at intervals of $^1/_{150}$ sec. The waves start from a source of sound *A*, and it is obvious that the front *B* of the "direct" wave is the first sound to reach every listener. The intensity of this wave decreases with the square of the distance from the source. Actually the direct sound will be even more weakened in many cases, since it passes over an audience which absorbs sound strongly. In such a case it may be assumed that the sound pressure, which is the determining factor in observation, is given by the current of sound energy which is incident upon one unit of area of the absorbing surface, and not by the intensity of the sound wave which would exist at that point in the absence of an absorbing surface. The sound pressure will therefore usually be very small, because the direct sound from a speaker or an orchestra nearly always travels in a practically horizontal direction, and a given area therefore receives energy from the source only within a very small solid angle. Only with loudspeakers, or by placing the speaker on a high projecting rostrum, is it possible to direct the sound toward the audience at a steep angle. Without these aids very little of the direct sound reaches the back of the hall.

In fig. 5 it will be seen, however, that it is at the back of the hall, where the direct wave is so much weakened, that a large number of reflected waves with slight differences in time reach the audience.

The question now is: to what degree can these waves help to increase the intelligibility?

## Useful and detrimental sound

Since the ear, like the eye, possesses the charac-

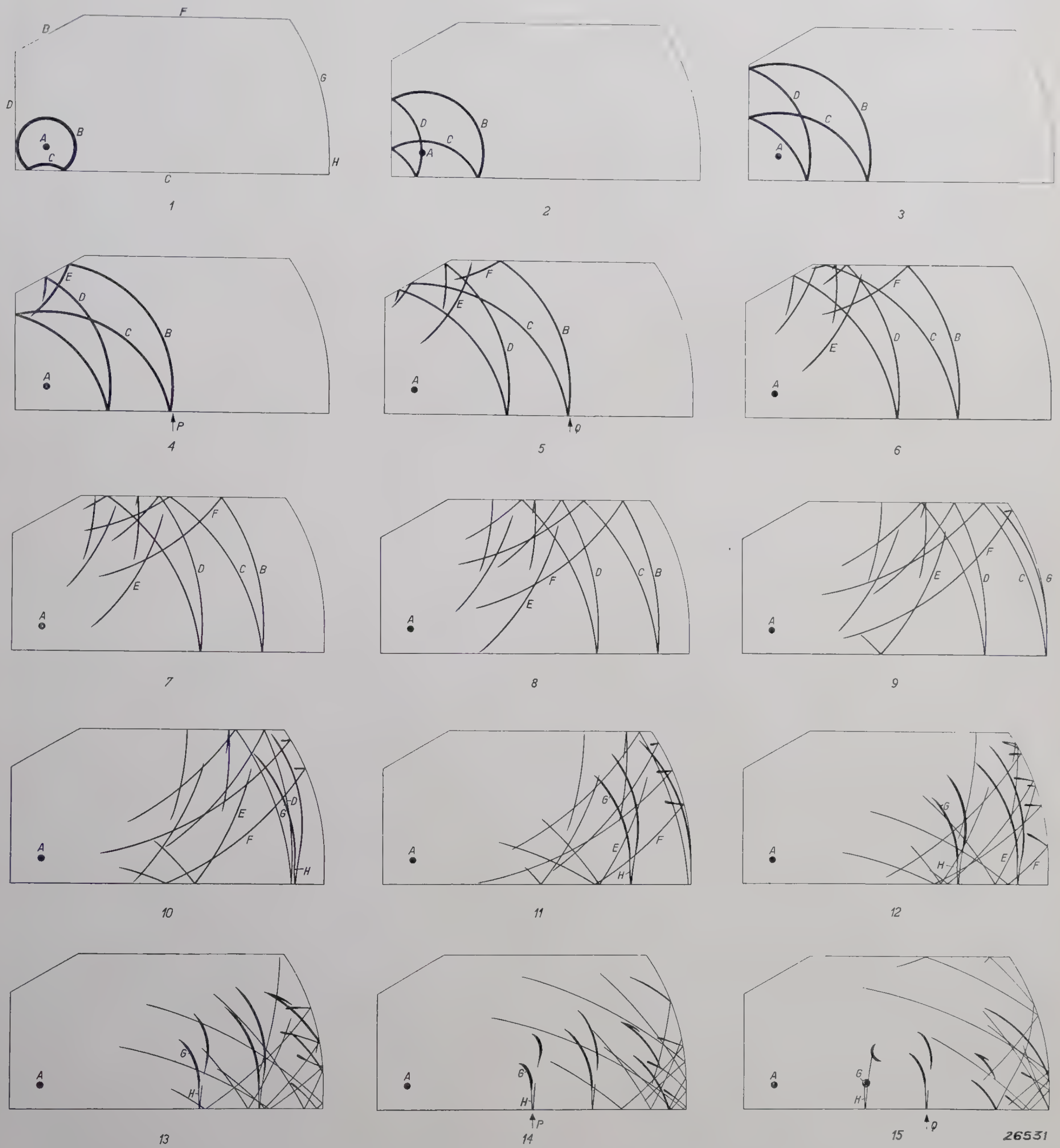


Fig. 5. Let the above figure represent the cross section of an auditorium. A source of sound is placed at *A*, and it begins to radiate at the moment $t = 0$. In the successive pictures the wave front is drawn at intervals of $^1/_{150}$ sec. The walls are considered to be completely reflecting, while the strength of the wave is represented approximately by the thickness of the lines. The waves are indicated by the same letters as the walls by which they are reflected. The most important of these are:

*B:* the "direct" wave, i.e. the wave which has not been reflected by any wall;
*C:* the reflection by the floor;
*D:* the reflection by the wall behind the source;
*E:* the reflection by the sloping roof above the source;
*F:* the reflection by the ceiling;
*G:* the reflection by the curved rear walls;
*H:* the reflection by the vertical part of the rear wall.

Because of the complexity of the combinations of repeated reflections, it is impossible to continue this method of indication consistently.

teristic of blending stimuli received during a certain period of time to a single impression, the waves which are incident one after another can reinforce each other if their succession is rapid enough. The time within which the ear is unable to perceive successive reflections as separate from each other is of course not sharply limited, but it is of the order of $^1/_{15}$ sec. The waves in fig. 5, which reach the listener within $^1/_{15}$ sec after the first sound impression, therefore act together to increase the intelligibility: they are "useful" sound. That which comes later may be "detrimental" because of the fact that it is observed as a new impression and, as such, may be disturbing. It is now possible to find out in a simple way where "detrimental" sound first occurs in fig. 5. In the first 10 states only useful sound can reach the listener, since these 10 states occur within $^1/_{15}$ sec. In the next few states also the audience receives no "detrimental" sound, because at those places reached by reflected sound the direct wave *B* is incident only several hundredths of a second after the source has begun to work. From a comparison of the 4th with the 14th state and of the 5th with the 15th, it will be seen that at the points of the arrows *P* and *Q* respectively, the reflection of the rear wall is incident just $^1/_{15}$ sec after the direct sound. The wave *H*, which up to this moment as useful sound could make a contribution to the intelligibility, now begins to be detrimental. To an even greater degree is this the case with the wave *G* reflected by the curved rear wall and concentrated in a focus. This gives an excessively reinforced sound wave which arrives 0.08 sec later than the direct wave. It is distinguished from the other reflections which make up the reverberation by its greater intensity, and is therefore observed separately as an echo.

The analysis as carried out in fig. 5 is too time-consuming for practical application and, moreover, it extends only over $^1/_{10}$ of a second. It must usually suffice to find out how much energy the different parts of the audience receive from the direct beam and from the principal reflected waves which differ in length of path covered by not more than 20 metres (difference in time about $^1/_{15}$ sec). This can be done quite simply by drawing a beam of sound rays starting from a speaker at various suitable places, and following these rays through their first and sometimes second reflection, until they reach the listeners. It must hereby be kept in mind that the aim is to throw the sound as much as possible on the audience and, in addition, to distribute the available energy as uniformly as possible to prevent one listener from obtaining too much at the expense of another.

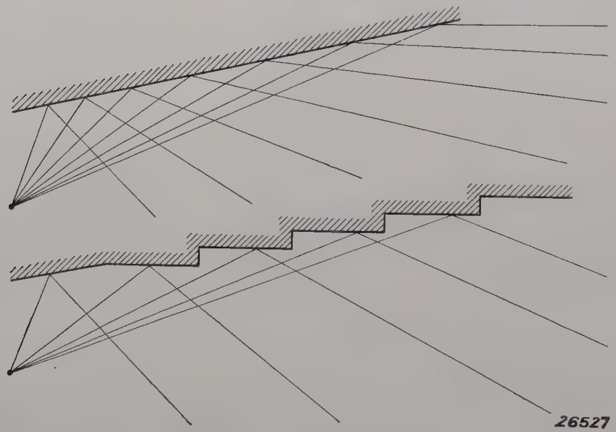


Fig. 6. If it is necessary that the ceiling of an auditorium should be higher at the rear it can to advantage be constructed in the form of steps.

In this investigation those rays of sound are also discovered which differ in length of path by more than 20 metres from the direct sound, and which therefore, if they are sufficiently intense, can give rise to an echo.

### Influence of the shape of the hall

In connection with the foregoing we shall discuss several points about the influence exerted by the shape of the hall and its walls on intelligibility. This discussion cannot be a complete one, but only an explanation of the ways in which the useful sound can be increased and the detrimental sound decreased.

*Useful sound*

As we have already shown, except with a raised source of sound (a loudspeaker for example), the direct sound radiation will only be of importance for the first rows of seats. The rest of the audience will have to rely upon sound reflected by the walls. The ceiling, considered as one of the walls, will fulfil the most important function in this reflection, and a plane surface will in ordinary cases be found favourable. The front part of the ceiling, however, throws the sound into the front of the hall where it is not needed, and it is therefore an advantage to make this part of the ceiling sloping as shown in fig. 5 at *E*. The rear wall also, especially under the balcony, becomes effective if it leans forward at a suitably chosen angle. In some cases there will be a conflict between the position of a wall desirable for other reasons and that necessary for the correct reflection of sound. This is true for instance when the ceiling slopes upward toward the rear, whereby too much sound is reflected to the extreme rear of the hall. A step-shaped design, as indicated in *fig. 6* may then often solve the difficulty. Care must be taken not to exaggerate by carrying the principle of the reflecting action of the walls too far. It will in general be satisfactory if the audience receives reflected sounds from several directions. This can, for example, be achieved by making the reflection somewhat diffuse in the transverse cross section. This is not only desirable for the more uniform distribution of the sound and for the greater independence of this distribution on the position of the source, but also in order to avoid the speaker being disturbed by noise from the public by a reversal of the ray diagram.

As a check on our calculations in the case of complicated shapes of halls, optical models can be made of the diagrams constructed. In these models,

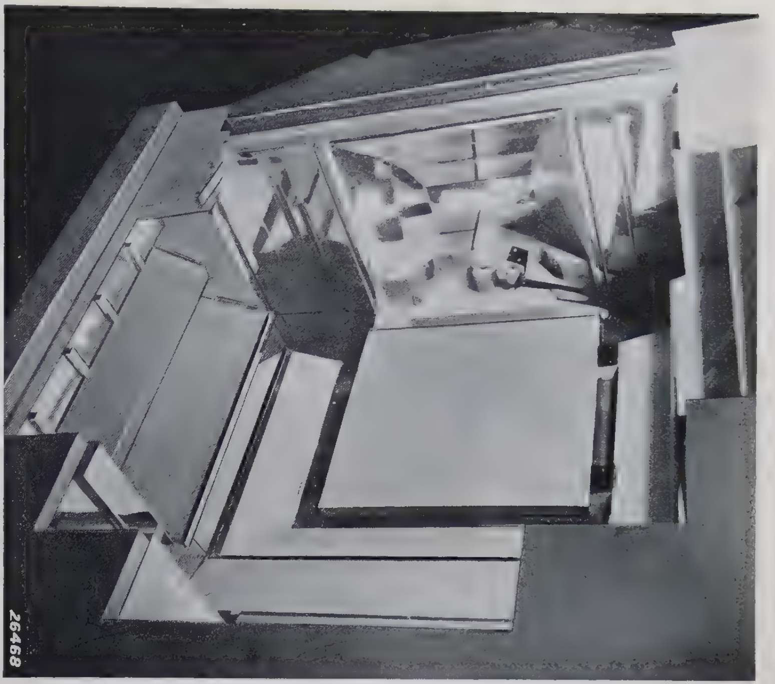


Fig. 7. Optical model of the large assembly hall in the League of Nations Palace in Geneva. The place of the speakers is represented by an electric lamp. At the intended positions of the audience, plates of frosted glass are introduced. The intensity of illumination at these places is a measure of the sound intensity available for the audience.

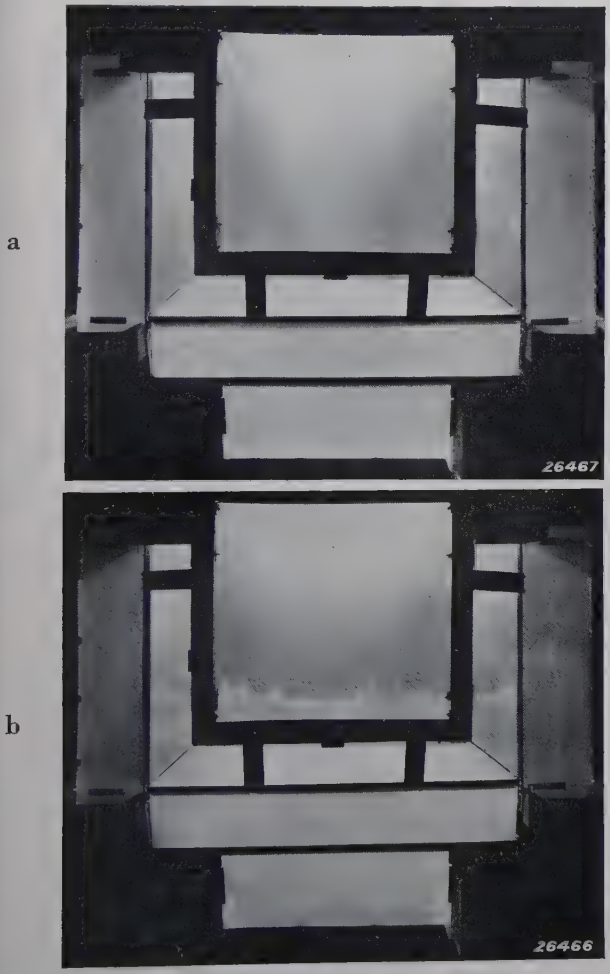


Fig. 8a). Distribution of light on the floor and rows of seats around the floor.
b). Distribution of light when the quasi-parabolic reflector behind the speaker rostrum is inactive. Not only at the rear but also along the sides of the hall is the illumination and therefore the sound intensity, less.

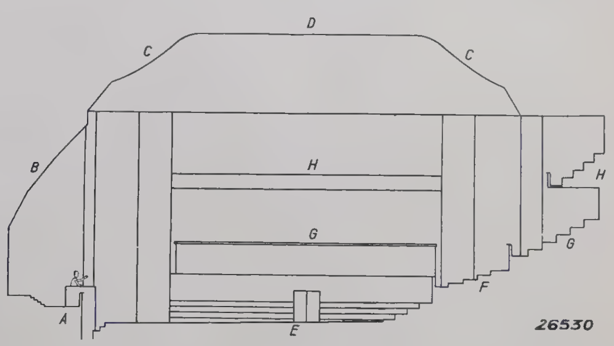


Fig. 9. Cross section of the large assembly hall in the League of Nations Palace. The speakers rostrum is at *A* and is surrounded by a marble sound reflector *B*. The ceiling is partially strongly absorbent (*C*), and partially occupied (*B*) by a glass lighting element. The audience is situated in the centre portion of the hall *E* and in the various balconies *F*, *G* and *H*.

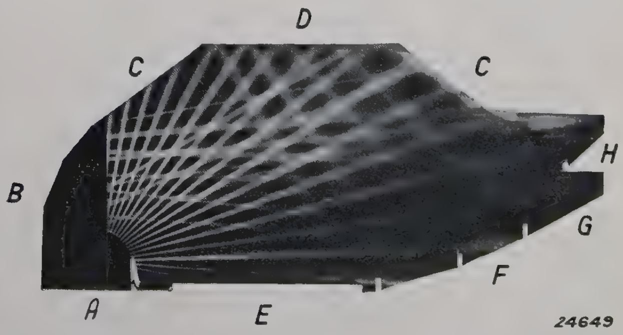


Fig. 10. Course of the sound rays in the large assembly hall made visible in the smoke-filled optical model. This figure makes particularly clear the importance of the ceiling and of the reflector for the distribution of sound in the direction of the horizontal axis of the room. The letters have the same significance as in fig. 9.

an example of which was described previously in this periodical [3]) the source of sound is replaced by a small lamp and the coefficient of optical reflection of the walls of the model are made to correspond somewhat to the acoustic coefficient of reflection in the actual structure. The intensity of illumination of every surface is then a measure of the sound intensity at that place.

In the attempt to detect the cause of undesired deviation the rays may be made visible by filling the model with a mist. *Fig. 7* shows such a model of the large assembly room of the League of Nations Palace in Geneva, the cross section of which is given in *fig. 9*. Figures *8a*, *b* and *10* illustrate several investigations carried out on this model. The inscriptions under the figures furnish an explanation.

*Detrimental sound*

Echo occurs especially in the case of concave curved surfaces, an example of which was given in fig. 5 at *G*. Such surfaces must therefore be avoided as much as possible, or, when they cannot be avoided experiments must be carried out to find out whether that shape is really permissible.
Such a form is permissible when the radius of curvature is sufficiently great: it may be assumed as a rule in the transverse cross section that a radius equal to twice the height is desirable. In that case the wave is projected on the audience as a fairly parallel beam.

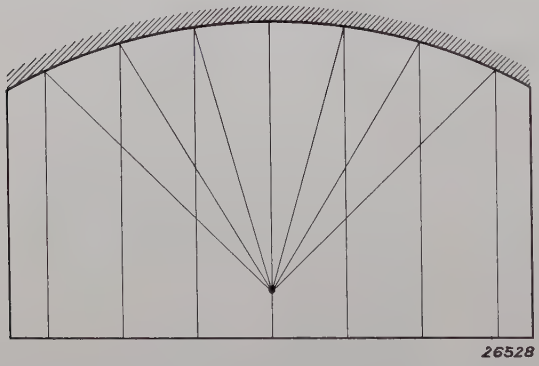


Fig. 11. By means of a ceiling with a radius of curvature of twice its height above the source of sound, the sound is reflected upon the audience in the form of a nearly parallel beam.

Cupolas must always be regarded with suspicion, as well as elliptical forms and the like. Rounded angles with a sufficiently small angle of curvature are often succesfully used. In such cases the focus must be far above the audience which serves to give a strong spreading of the sound. This method can be used to advantage in the angle formed by the ceiling and the rear wall which has a strong tendency to throw the sound back to the speaker as a disturbing echo.

If the reverberation is too strong and absorbing materials must be applied, the best places are the side walls which usually do not play an important part in the distribution of the useful sound.

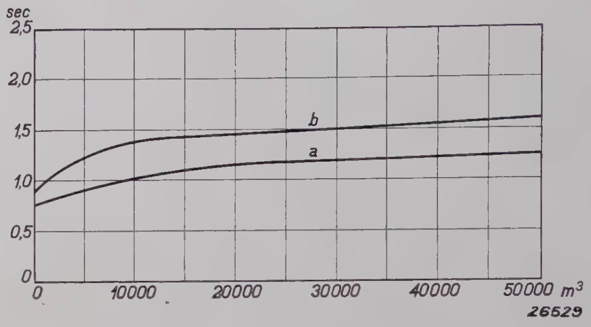


Fig. 12. Reverberation time for the spoken word as a function of the volume of the room, according to Knudsen. Upper curve: recommended values for ordinary theatre auditoria, lower curve: reverberation times at which intelligibility is at a maximum.

In general it is not wise to reduce the reverberation more than necessary; in the first place because the spoken word becomes dull and less pleasing, and in the second place because there is no sharp difference between walls which reflect useful and those which reflect detrimental sound, so that a decrease in reverberation is in fact always accompanied by a decrease in the intelligible sound. By means of measurements on a large number of halls with unusually good acoustics and on theoretical considerations, various investigators have found optimum values of the reverberation time. These values increase with the volume of the room (see *fig. 12*), which means simply that in large halls a longer reverberation must be allowed in order not to suppress the desired reflections (from the ceiling for example).

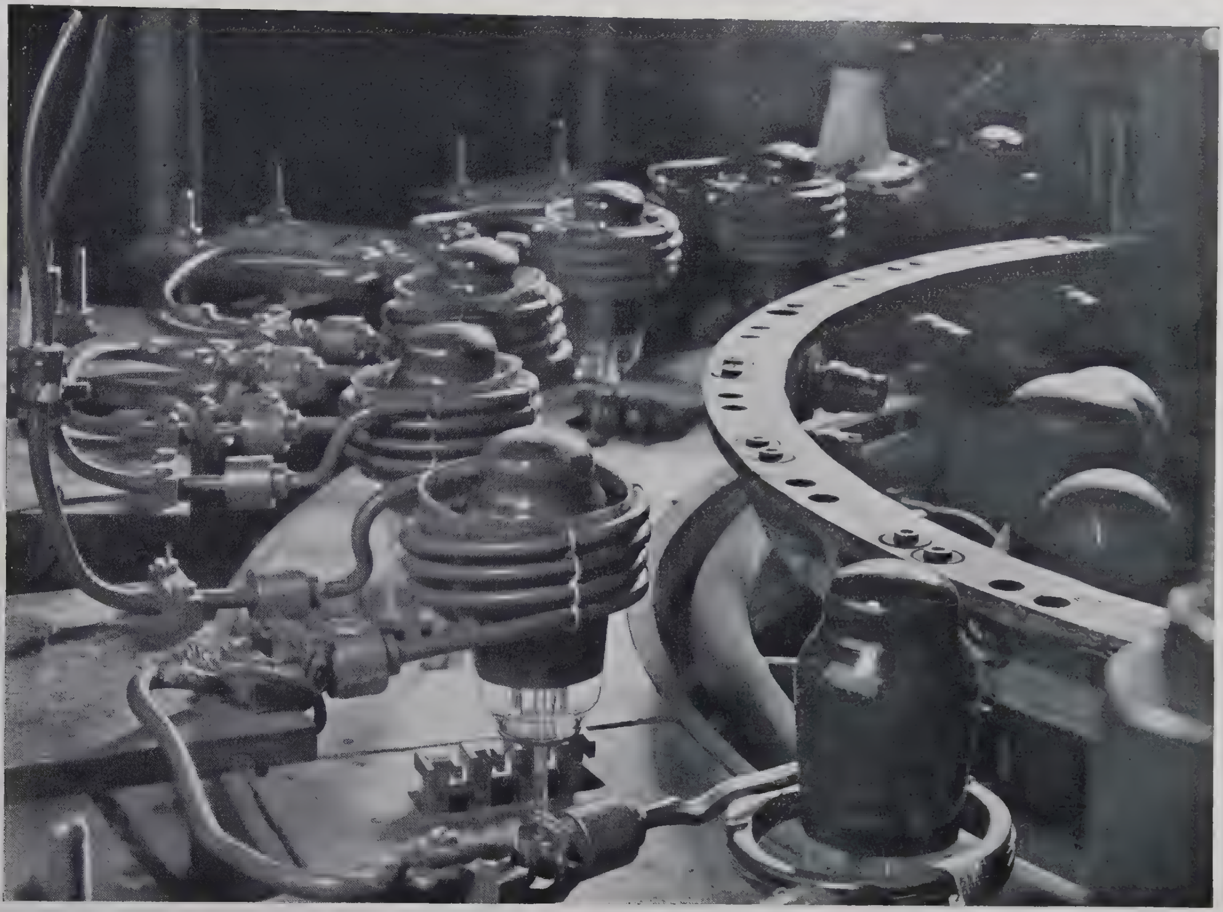
In general it may be said that the acoustics of a hall become pleasanter when the wall surfaces which do not contribute to the useful reflection are so constructed that they scatter the sound which is not absorbed. For this purpose a coarse rough surface is necessary since unequalities of the surface which are small with respect to the wave length of sound are ineffective.

In many cases it may be doubted whether modern architecture, with its preference for simple lines and smooth surfaces, is always as efficient from the standpoint of acoustics as it pretends to be.

---

[3]) R. Vermeulen and J. de Boer, Optical model experiments for studying the acoustics of theatres, Philips techn. Rev. 1, 46, 1936.

# PUMPING PLANT FOR RADIO VALVES



The illustration shows the method employed for evacuating radio valves. Unlike the evacuation of incandescent lamps great care must be taken here to outgas the parts mounted in the valve such as cathode, molybdenum grids and nickel anode. The rotating pumping plant has a number of points of connection which move through a series of positions on the circumference of a circle. Each connection point has its own pump which accompanies the valve from one position to the next. The small mercury vapour pumps have a common backing pump which is disconnected during the passage from one position to the other. The connection between the valve and the pump is formed by a thin glass tube. The inner parts are outgassed by means of high frequency fields induced by currents through spiral tubes lying around the valves at certain positions. These spiral tubes are connected in series and are supplied with current from an installation not visible in the drawing. At other positions the outgassing is continued by electron bombardment if necessary. The gas is liberated from the cathodes by electrical heating. In the photograph the electrical contacts for connecting grids, plate and cathode can be seen. The black coating on part of the bulb is for the purpose of eliminating secondary emission.

# APPLICATIONS OF CATHODE RAY TUBES II

by H. VAN SUCHTELEN.

621.317.755 : 621.385.832

In a previous article several examples were given of measurements with the cathode ray oscillograph on various electric mains. We shall here discuss several typical oscillograms of current or voltage in apparatus connected to the mains.

## Oscillograms of gas discharge lamps

Our first examples are the voltage oscillograms recorded with two types of gas discharge lamps, namely the sodium lamp SO 650 and the super high pressure mercury lamp HP 300.

A discussion of the functioning and characteristics of these would be out of place in this article. Several peculiarities may, however, be pointed out, since they are particularly striking in the oscillograms.

In *fig. 1* four oscillograms are recorded of the voltage on the lamp when it is supplied from 50 cycle A.C. mains. In the upper half next to each other are those of the sodium lamp, first just after being switched on, and then after it has become warm in normal use. Those of the mercury lamp are given below, first cold and then warm.

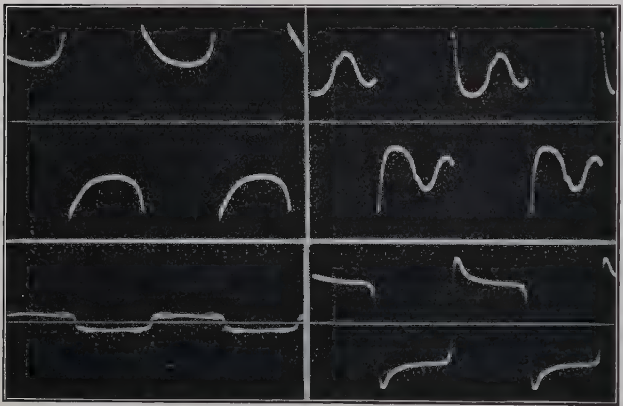


Fig. 1. Voltage of a sodium lamp (above) and of a mercury lamp (below). Left: immediately after being switched on, right: in the working state.

In the first oscillogram the discharge takes place in an atmosphere of neon, no sodium has yet been vaporized. It may be seen that the voltage over a large part of every half period is fairly constant. The fact that, with the exposure time chosen in this case, the photograph of the oscillogram seems to be interrupted between the positive and negative half periods is due to the extremely rapid alternation of the voltage of the lamp after the interruption of the discharge.

After the lamp has become warm the oscillogram takes on a different character. The voltage at which the discharge begins remains about the same, but the working voltage is lower since the discharge now takes place in an atmosphere of sodium. In the middle of the half period, however, there are not enough sodium atoms for ionization and the voltage curve moves toward the level of the neon discharge, since neon atoms must now be ionized. After a half period the current alternates.

A phenomenon which is very well illustrated in this oscillogram is the appearance of "striae". Immediately after the inset of the discharge (in the descending branches) it may be seen that the line is dotted. This indicates that an alternating voltage of much higher frequency is superposed on the curve for the voltage under discussion. The appearance of this fluctuation must be explained in the following way: along the path of the discharge there are points where there is a quite sudden voltage jump. These discontinuities which are called "striae", whose mechanism is not yet entirely clear, usually run from one electrode to the other, and whenever such a point arrives at an electrode the total lamp voltage changes by the amount of the voltage jump in question.

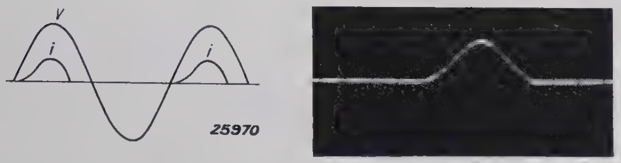
In the oscillogram of the mercury lamp which has just been ignited (lower left) one sees again a discharge under relatively low pressure, since there is as yet only a small amount of mercury vaporized. (The fact that a change was taking place during the time of the exposure may be seen from the appearance of a double line).

When the lamp has become warm and the mercury is vaporized, both the breakdown voltage and the practically constant working voltage are much higher. In the high pressure mercury lamp the amount of metal vapour available is always sufficient to carry the discharge, so that the rare gas also present (ignition gas) no longer plays a part. In contrast to the second oscillogram, the working voltage in this case remains fairly constant.

## Oscillographic investigation of a disturbance

A case which was investigated many years ago by means of the cathode ray oscillograph, was that of the occurrence of a rattling noise superposed on the output of an audio amplifier. The first oscillogram of the loudspeaker circuit immediately showed that the disturbance occurred fifty times per second, so that suspicion immediately fell on the supply arrangement of the amplifier. The fact that such disturbances may occur when gas-filled rectifiers are used was known, but with the high vacuum rectifier used here such a disturbance was not immedately to be expected, since the characteristic of a high vacuum rectifier, while not linear, nevertheless exhibits no great discontinuities.

The current through the rectifier is connected to the alternating voltage, as is shown in fig. 2a for single phase rectification. The passage of the current lasts less than a half period, due to the fact that the counter voltage of a battery or a charged condenser must first be overcome.



*a* *b*

Fig. 2. Variation of the current through a rectifier valve.

In *fig.* 2b the oscillogram is given of the current through the high-vacuum rectifier valve. To the left may be seen the passage of current during a part of the half period, to the right the horizontal part which indicates that the current cannot flow in the other direction.

While during the growth of the current on the extreme left the transition from the horizontal line takes place quite uniformly, there is a fairly sharp angle at the beginning of the blocking period. That is to say, to the left before this point there is a change in the current, while immediately afterwards d$i$/d$t$ becomes equal to zero. The current now passes through the secondary winding of the transformer with its leakage inductance $L_s$ (see *fig. 3*). As long as there is a definite value of d$i$/d$t$, it causes a counter e.m.f. in the leakage inductance $v = -L_s\,\mathrm{d}i/\mathrm{d}t$, while this voltage disappears as soon as d$i$/d$t$ = 0. This voltage component must of course be considered to be superposed on the normal alternating voltage of the secondary winding.

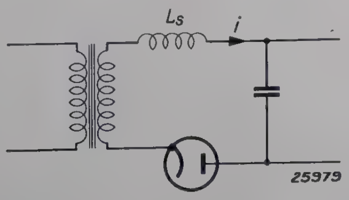


Fig. 3. Circuit diagram of a rectifier valve.

In *fig. 4* is given the oscillogram of the voltage on the secondary winding, and it may be seen that there is actually a sudden jump just after the maximum of the sine curve. This is, therefore, the moment when $L_s$ d$i$/d$t$ suddenly becomes equal to zero. The fact that the phenomenon is very rapid, much more rapid than was expected, appears from the fact it is manifested as a break in the oscillogram.

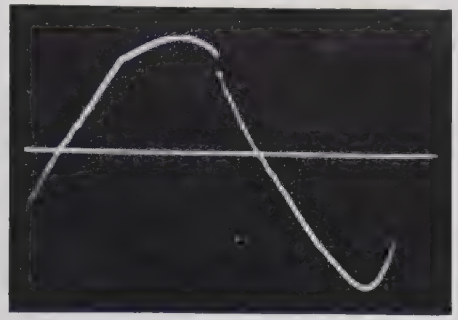


Fig. 4. Variation of the voltage in the secondary of the transformer of fig. 3. The moment at which the current through the rectifier valve is interrupted is distinguished by a voltage jump.

The fact that such a voltage jump at the terminals of the secondary of the transformer can influence the grid of an amplifier valve by capacity coupling is obvious, and the source of the disturbance is thus definitely discovered.

One of the methods of removing such a disturbance is by bridging the secondary of the transformer with a condenser. It is theoretically impossible for such abrupt voltage jumps to occur across a condenser. The effect of a condenser of 0.1 μF is shown in *fig. 5*. The presence of a jump in voltage may still be seen clearly. But from the fact that the curve is continuous, it may be inferred that the

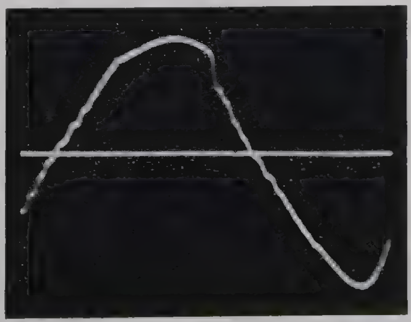


Fig. 5. Variation of the voltage in the secondary of the transformer of fig. 1 when a condenser is connected across the terminals of the secondary. The discontinuity is less sharp.

phenomenon takes place much more slowly. This has been found in practice to be sufficient to prevent a transmission of the effect to the sensitive points in the amplifier.

That without this preventive measure the voltage jump contains very high frequencies is shown by the fact that under certain conditions such interferences also occur in radio receivers, where they are even able to penetrate by way of the aerial and aerial circuits tuned to radio frequencies. This effect is shown in *fig. 6* where the transformer voltage and the intermediate frequency voltage, measured on the intermediate frequency amplifier of a radio set which was weakly coupled with the rectifier, are reproduced on the same oscillogram. There are now two breaks in the oscillogram of the transformer voltage which may be ascribed to the above-mentioned phenomenon in the two-phase rectifier. The horizontal straight line indicates the time axis, and therefore zero voltage. Just under the breaks in the transformer oscillogram may be seen the rapidly damped intermediate frequency oscillations, one somewhat stronger than the other.

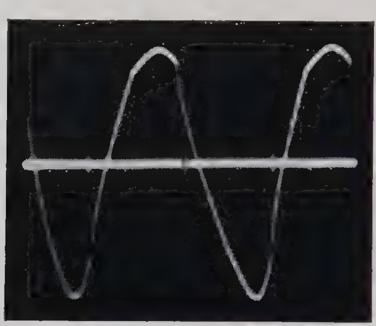


Fig. 6. Intermediate frequency voltage of a radio set (heavy horizontal line; the individual oscillations are not separated from each other), and voltage on the transformer of the supply arrangement. The discontinuities in the transformer voltages (breaks in the curve) lead to vislent, strongly damped, intermediate frequency oscillations.

**The recording of several curves on one oscillogram**

The last case mentioned above was an example of the recording of two curves on one oscillogram. Such records are desirable in other cases also, in order to be able to ascertain the coincidence or the phase shift of characteristic points. There are different methods of producing this result, two of which we shall describe.

The method by which fig. 6 was obtained is the simplest one. The time axis voltage is synchronized with the voltage of the mains with which the apparatus to be investigated is connected. The portable cathode ray oscillograph, type 3952, is especially constructed for this purpose. With this external synchronization a photograph is first made of the transformer voltage and then, on the same plate, one of the intermediate frequency voltage. Since both phenomena are fixed with respect to the mains voltage, the correct mutual relation is obtained. In this way it is possible to superpose any number of oscillograms over each other.

Although this method is very practical for the photography of oscillograms, it is useless for visual observation unless it is sufficient in each case to indicate by points on the screen the characteristic points of the curves. A picture like that of fig. 6 directly on the screen of the cathode ray tube would be preferable.

In order to achieve this, use must be made of one of the circuits which are sometimes termed "electron switches". The principle is as follows. The two voltages are applied in very rapid alternation (very rapid compared to the frequency whose oscillogram is being examined) to the pair of vertical plates of the oscillograph. A double oscillogram is then built up as shown in *fig. 7*. Actually, however, the frequency of commutation is taken so high (15 000 cycles/sec, for example) that an apparently continuous line is obtained.

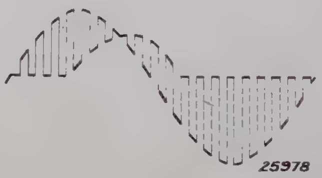


Fig. 7. Movement of the electron beam when two oscillograms are traced simultaneously.

The pinciple of the electron switch is given in *fig. 8* from which details have been omitted. The valves $L_1$ and $L_2$ are amplifier valves with a common anode resistance $R$, which amplify the voltages to be measured, $v_1$ and $v_2$, respectively. However, both valves never work at the same time. The screen grids are not connected to a constant voltage, but to a "square-topped" alternating voltage. The screen grid of $L_2$ is negative when that of $L_1$ is positive and vice versa. The valve with positive screen grid gives a certain amplification, that with negative screen grid passes no signal at that moment. In this way reproductions of $v_1$ and $v_2$ are obtained alternately on the resistance $R_1$ coupled with the oscillograph, as indicated in fig. 7.

The "square top" alternating voltage for control of the screen grids is obtained from a multivibrator. This consists of two valves $L_3$ and $L_4$, which are mutually coupled by the condensers $C_3$ and $C_4$. We shall explain briefly the functioning of the circuit.

If one assumes that, due to some cause or other, the grid of $L_3$ becomes more negative, the current through $L_3$ and thus the voltage drop on $R_3$ decreases, and the anode therefore becomes more positive. The latter is, however, coupled to the grid of $L_4$ which then also becomes more positive. On the other hand the anode of $L_4$ becomes more negative. This anode is again coupled with the grid of $L_3$, our starting point. This grid, therefore, becomes more negative, and it is clear that the first assumption introduces an unstable condition in which the first grid becomes more and more negative.

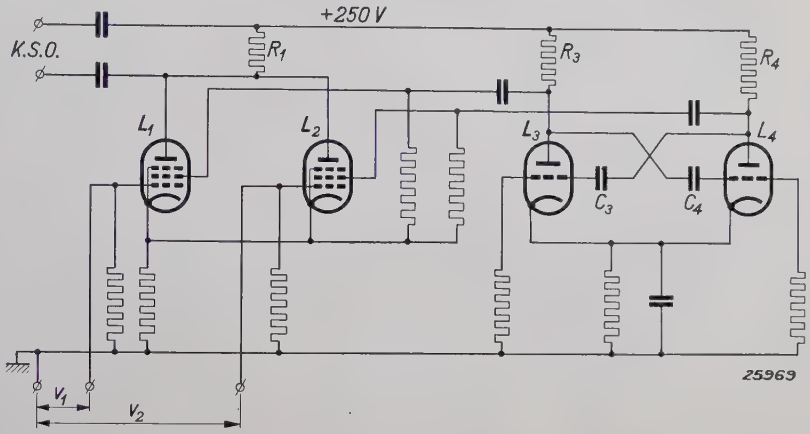


Fig. 8. Diagram of the circuit by means of which the voltages $v_1$ and $v_2$ are applied alternately to the deflection plates of the cathode ray oscillograph.

The anode of $L_3$ rapidly becomes positive, that of $L_4$ negative. The two amplitudes are, however, limited by the available anode voltage of the supply apparatus, here indicated as 250 volts. As soon as this limit is reached there is a quiescent interval, during which period the anodes keep the voltages they have attained and the grids begin to take on their original voltages again.

As soon, however, as the anode voltage of $L_3$ begins to fall again, another unstable condition is introduced which is just the reverse of the one described above. In this way the two anode voltages vary in opposite phase regularly back and forth between two limits, and thereby block alternately the two valves $L_1$ and $L_2$. The oscillograms of *fig. 9* were recorded with the aid of such a circuit. These curves refer to a high pressure mercury lamp. Figs. 9*a* and *b* give the lamp current and lamp voltage, immediately after switching on the lamp when it was still in the "cold" state. The pure sine curve is the mains voltage. Figs. 9*d* and *e* give the same data after the lamp has become warm.

In such combined oscillograms the phase relation is naturally the most striking characteristic. In fig. 9*a* the phase shift between mains voltage and current consumed is nearly 90°. While the lamp is warming up this shift may be seen on the oscillograph to decrease gradually, while at the same time the current also decreases slowly (fig. 9*d*). This illustrates an important characteristic of gas discharge lamps. It is well known that account must be taken of the current intensity in choosing the material of the leads, etc., but the power actually consumed is much less than would follow from the product of current and voltage. A low "power factor" must be taken into account.

Oscillogram *b* again shows the fairly low working voltage of the still cold lamp (all voltages are reproduced on the same scale) and also the large phase shift. During warming up the lamp voltage increases to that shown in fig. 9*e*. It may be seen that the ignition voltage remains lower than the mains voltage.

While these combined oscillograms are extremely useful for direct observation, it will perhaps sometimes be desired to combine even more curves for the sake of illustration. For example it might be desired to demonstrate that the lamp current and voltage of figures *a* and *b*, and *d* and *e*, respectively, are in phase. This can be done since there is no objection to applying the method first discussed to this case, namely that of making two exposures on one plate. In fig. 9*c* an exposure was first made of the current curve with a zero axis, and then on the same plate and with the same synchronization an exposure like 9*b* with the result that all the curves are combined in one picture. The same method was used to obtain fig. 9 *f*, and in this case particularly it may be seen very clearly that lamp current and voltage are in phase but that both are shifted in phase with respect to the mains voltage.

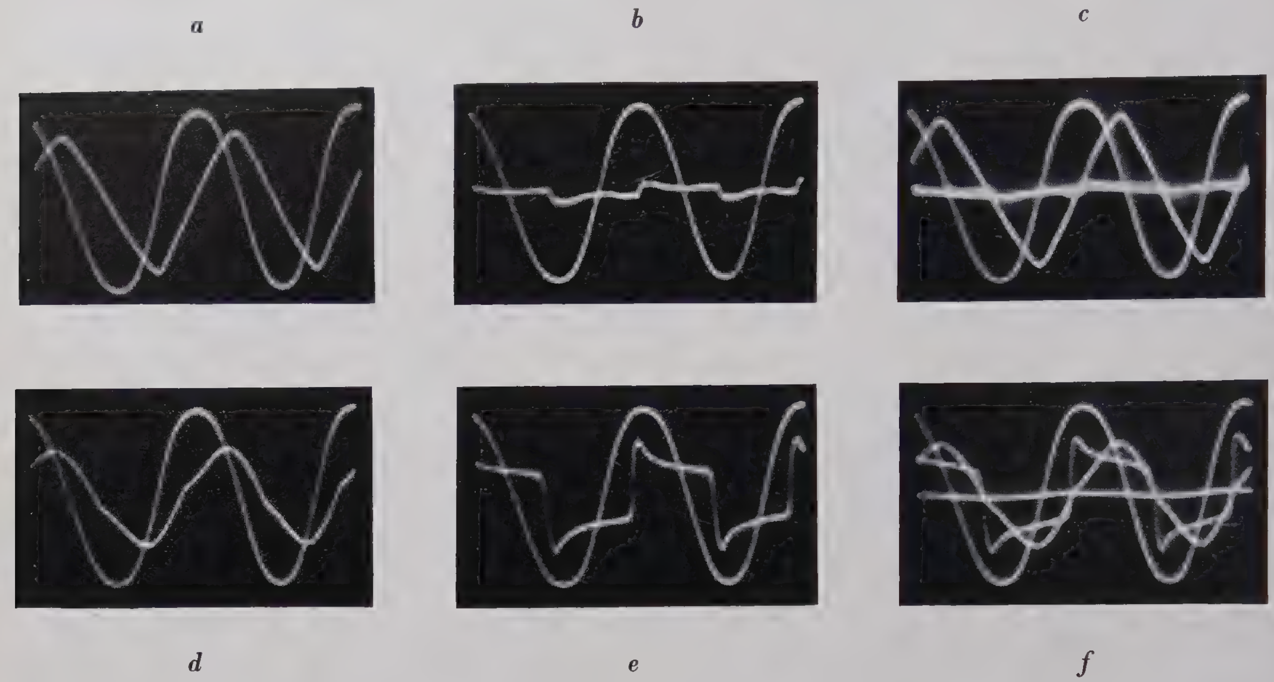


Fig. 9. Various combined oscillograms. Upper row: cold mercury lamp; lower row mercury lamp in working condition. The sine curve in each case represents the mains voltage.
*a* and *d* current combined with mains voltage;
*b* and *e* lamp voltage combined with mains voltage;
*c* ans *f* current, mains voltage and lamp voltage combined.

# REVIEW OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS GLOEILAMPENFABRIEKEN

**1263:** J. H. de Boer and H. H. Kraak: Aktivierte Adsorption von Sauerstoff an Molybdänschichten (Rec. Trav. chim. Pays-Bas **56**, 1103 - 1110, Nov. 1937).

When thin metal films come into contact with oxygen recrystallisation occurs and an oxide is formed on the surface, as may be seen from a change in the electrical conductivity. The second effect can be measured separately in the case of molybdenum. Only a very small portion of the surface atoms hold the oxygen by chemical bonds at — 185° C. Van der Waals' adsorption, which causes no change in resistance, also takes place at this temperature, as was demonstrated by the increase of oxidation upon warming the film in a vacuum. As was expected, the activation energy of the oxidation increases in the order: caesium, molybdenum and carbon.

**1264:** Balth. van der Pol and H. Bremmer: The diffraction of electromagnetic waves from an electrical point source round a finitely conducting sphere, with applications to radiotelegraphy and the theory of the rainbow. (Phil. Mag. **24**, 141 - 176 July 1937, and 24, 825 - 864, Suppl. Nov. 1937).

The diffraction about a sphere of electromagnetic waves from a point source outside the sphere is investigated in different ways. In the first place Watson's method is described, which consists in the transformation of the infinite series of spherical functions for the Hertzian vector into another series which converges much more rapidly for wave lengths which are small with respect to the dimensions of the sphere. A large number of numerical results are given for the case where the point source represents a radio transmitter which may lie either on the surface of the conducting sphere or at a small distance from it, and where the conductivity and the dielectric constant of the sphere may have different values. This method is compared with that in which there is a development in characteristic functions, which latter shows analogy with methods used in the treatment of the vibrating string and in wave mechanics.

In the further treatment the original harmonic series for the Hertzian vector is divided into an infinite sum of other harmonic series. Each of these series may be considered as the description of a train of waves which are reflected one or more times at the inner surface of the sphere. For every high frequency these waves pass over into rays. These series may be approximated by means of a saddle point development. This method gives good approximations for the field of a radio transmitter in the region above its optical horizon. If the point source is at infinity, we obtain a strict interpretation of the well-known theory of Airy for the intensity of the light of the rainbow.

**1265:** Balth. van der Pol: Propagation of short waves over a spherical finitely conducting earth (Ref. u. Mitt. Int. Kongr. Kurzwellen, Wien, 1937, pp. 34 - 35).

In this lecture the International Congress on Short Waves (Vienna 1937) the same subject was discussed as in **1264.**

**1266:** K. Posthumus: Kurzwellenröhren (Ref. u. Mitt. Int. Kongr. Kurzwellen, Wien 1937 pp. 78 - 88).

In this lecture a survey was given of the different kinds of valves for the excitation, amplification and modulation of high frequency oscillations. From the method of functioning of the triode generator it is deduced that it can only generate ultra short waves of several metres wavelength with a reasonable efficiency when care is taken that the transition times of the electrons in the valve are sufficiently small. Valves are then discussed whose action depends upon the occurrence of Barkhausen oscillations, and magnetrons with a single anode and with several anodes. With this latter type of magnetron it is possible with air cooling to emit an energy of 60 W at a wave length of 60 cm with a efficiency of 50 per cent. The modulation of these magnetrons is obtained by allowing them to radiate for longer or shorter periods at full power with intervals of non-radiation between, the intermittency being of supersonic frequency.

Finally means are indicated for providing that, upon amplification, the frequency of the amplified oscillation will be determined exclusively by the frequency of the modulating transmitter.

**1267:** W. G. Burgers, J. D. Fast and F. M. Jacobs: Zug- und Rekristallisationstextur von Zirkondraht (Z. Metallk. **29**, 410 - 412, Dec. 1937).

By hammering and drawing a zirconium rod in an iron jacket without any heating, a zirconium wire is obtained which shows unusually plainly a drawing texture. This texture is distinguished from that of a normal wire by the fact that not only the basic plane (0001) but also a diagonal axis of the second sort (1010) is parallel to the axis of the wire (with a certain spreading). Upon recrystallization a texture appears which deviates from the drawing texture. With the same position of the basic plane in this case a diagonal axis of the first sort (1120) lies parallel to the axis of the wire. Upon heating above the transition temperature and cooling to room temperature this texture remains.

**1268:** J. L. Snoek: Scattering of X-Rays by conduction electrons in metals (Ned. T. Natuurk. 4, 236 - 244, 1937).

From the spectral composition of the random scattering of X-rays, i.e. from the form of the Compton line, it follows that the velocity distribution of the conduction electrons in a metal is not that given by Maxwell, but that given by Fermi. On a proposal by Debye, Scharwächter investigated in 1937 the variation of the intensity of the Compton small angle scattering of beryllium. The variation found experimentally is found to agree reasonably well with the variation of intensity calculated theoretically for two "free electrons" and not with that for one or three.

**1269:** J. H. de Boer and J. F. H. Custers: Absorption by Van der Waals' forces and surface structure. (Physica 4, 1017 - 1024, Nov. 1937).

In many cases gases and vapours are adsorbed by means of non-polar Van der Waals' forces. From the adsorption energies observed it follows that a porous structure of the surface is necessary to cause adsorption by means of Van der Waals' forces. Upon the absorption of light by molecules which are adsorbed on layers of salts deposited by sublimation in a vacuum the Van der Waals' adsorption can be distinguished optically from adsorption in which electrostatic forces also take part. In the case of iodine the Van der Waals' adsorption gives a brown coloration and with caesium a blue coloration. Layers of alkali and alkaline earth halides deposited by sublimation in a vacuum are very porous and become very brown in iodine and blue in caesium. Layers of $SiO_2$, $Al_2O_3$, $ZrO_2$ and $AgC_1$ prepared in the same way show a compact structure and are not coloured; powders of these substances on the other hand absorb strongly and become deeply coloured. Upon sublimation in an atmosphere of argon, $SiO_2$ is also obtained in the form of a porous layer which adsorbs iodine well.

The layers of $SiO_2$ deposited in a vacuum, however, are also found to adsorb caesium or iodine. From the absorption of light by caesium which is adsorbed on layers of $SiO_2$ deposited in a vacuum it follows that the caesium is only adsorbed as individual atoms, as is also the case in the very first stages of the adsorption on $CaF_2$. On the other hand no Van der Waals' adsorption could be shown. The behaviour of caesium on $Al_2O_3$ and of iodine on $SiO_2$ agrees with this. A porous surface is necessary for the attainment of adsorption exclusively by Van der Waals' forces.

**1270:** A. Th. van Urk: On the cohesive forces of liquids with simple molecules and the so-called law of Stefan. (Physica 4, 1025-1033, Nov. 1937).

Stefan's law is still encountered in handbooks of physics. This law is that "the work necessary to bring a molecule from the depths of a liquid to the surface is equal to one half the heat of vaporization". This, however, is not even valid by approximation, as is proved in this article both experimentally and theoretically. The correct ratio is 1/4 or even less; for hydrogen only it is 0.4.

**1271:** J. H. de Boer and G. Heller: Die Anisotropy der Van der Waalschen Kräfte. (Physica 4, 1045 - 1057, Nov. 1937).

The orientation of molecules under the influence of the Van der Waals' combining forces has the following causes:

1) the additive character of the Van der Waals' forces which tries to arrange the molecules in such a way that each atom has as many "neighbours" as possible and
2) the anisotropy of the tendency to polarisation, which favours a situation such that the axes of greatest polarizability lie in the line joining the molecules.

These two effects usually oppose each other. In general 1) dominates, so that long molecules lie side by side and ring shaped molecules lie with their planes parallel. With diatomic molecules, however, 2) might possibly be the stronger; and the molecules then take up positions with their axes end to end. Both effects also appear in the attraction of a molecule by a solid wall. Only at sufficiently great distance from the wall can the anisotropy be the more important, but it seems improbable that at such great distance the orientation forces would be important.

**1272:** H. C. Hamaker: The London-Van der Waals attraction between spherical particles (Physica **4**, 1058 - 1072, Nov. 1937).

It is obvious that the adhesive forces between small particles may be ascribed in a large degree to the combining forces of London and Van der Waals. In order to discover something about their order of magnitude the London-van der Waals forces are calculated between two spheres. These forces depend only upon the ratio between the sphere diameters and their mutual separation. A table of numerical data is compiled. For the case in which the mutual separation of the particles is small approximations to the derived formulae are indicated. Finally the change in the results is studied when particles are immersed in a liquid. It is found that in this case also the combining London and Van der Waals forces always produce an attraction.

**1273:** J. D. Fast: Zirconium (Foote Prints Chem. **10**, 1 - 24, Dec. 1937).

In this article several particulars are given about the preparation of ductile zirconium by thermal dissociation of $ZrI_4$. Some discussion is devoted to the use of zirconium in transmitter valves, where it is employed for three different purposes. One of these applications is based on the unusually high solubility of nitrogen, oxygen and hydrogen in solid zirconium. The article gives in addition a survey of the work done in the last seven or eight years by various investigators on the subject of metallic zirconium and zirconium oxide with special emphasis on systems consisting of ZrO and other oxides which are fusible with difficulty, and on alloys of zirconium with other metals. Various observations which have not yet been published elsewhere are included in this survey.

**1274:** F. M. Penning and J. H. A. Moubis: Eine Neutronröhre ohne Pumpvorrichtung (Physica **4**, 1190 - 1199, Dec. 1937).

A discharge tube is described in which neutrons are produced by bombardment of a plate of zirconium, loaded with heavy hydrogen, with ions of heavy hydrogen. With the aid of a magnetic field a glow discharge can be maintained with a potential difference of only a few kilovolts at a pressure of about $10^{-3}$ mm. This acts as a source of ions, so that it is not necessary to have a pump connected between the source of ions and that part of the tube where the ions are accelerated. In a certain case the number of neutrons produced by the tube was equal to that of a mixture of radium and beryllium of about 10 milli-curies. This number can be made considerably greater by water-cooling of the plate which is bombarded by ions.

**1275:** F. A. Heyn: The radioactivity of nickel, copper and zinc (Physica **4**, 1224 - 1228, Dec. 1937).

The radioactivity of nickel, copper and zinc excited by neutrons of varying energies was investigated. Several new nuclear reactions were found.

**1276:** W. de Groot: The relation between penetrating power and velocity of various elementary particles (Ned. T. Natuurk. **4**, 268 - 275, Dec. 1937).

In this lecture before the Netherlands Physical Society, on the basis of experimental data of Mano, Briggs and others the relation was discussed which exists according to a formula of Bethe between the ranges of various heavy charged particles ($\alpha$-particle, proton and deuton). For different particles the range in relation to the velocity can be deduced from the same graphic representation with the use of different scale values. For the energy region from 10 to 100 kilo-electron volts this curve is fairly valid even for electrons. It is pointed out that in the literature on nuclear reactions the atomic stopping power is often erroneously assumed to be proportional to the number of charges of the nucleus. Finally several measurements on Lenard rays are discussed.

**1277:** J. H. de Boer: Interpretation of molecular phenomena by means of potential curves II. Light absorption by adsorbed atoms and molecules (Ned. T. Natuurk. **4**, 276 - 283, Dec. 1937).

A discussion is given of the absorption of light by molecules and atoms which are adsorbed on a solid wall. Selective photoeffect and thermionic emission of electrons are treated for crystals upon which alkali metal atoms are adsorbed.

**1278:** J. H. de Boer: Interpretation of molecular phenomena by means of potential curves III. Photoelectrical conductivity, semi-conductors (Ned. T. Natuurk. **4**, 284 - 290, Dec. 1937).

The properties are discussed of crystals which contain an excess of electropositive or electronegative atoms. The theory of semi-conductors is treated.

**1281:** N. F. Moerman: Die Kristallstruktur des Azetaldehydammoniaks $CH_3 \cdot COH \cdot NH3$ (Z. Kristallogr. A **98,** 447 - 455, Febr. 1938).

From investigation of the crystal structure it is found that aldehyde ammonia crystallizes in the rhombohedral system according to the space group. $D^5{}_{3d}$. In an elementary cell there are six $CH_3 \cdot COH \cdot NH_3$ molecules present, but from a determination of the positions of the atoms in space it is found that these molecules in no way form the elementary units of the lattice. A complicated polymerization takes place, in which an important part is played by secondary valence forces, analogous to those which hold together the water molecules in an ice crystal.

**1282:** H. Bruining and J. H. de Boer: Secondary electron emission, part I. Secondary electron emission of metals (Physica **5,** 17 - 30, Jan. 1938).

For the contents of this article the reader is referred to the article contributed by H. Bruining in Philips techn. Rev. **3,** 80, Mar. 1937.

**1283:** J. Zernike: The Beilby layer; structure and occurrence of polished surfaces (Chem. Weekbl. **35,** 28 - 33, Jan. 1938).

A survey is given of investigations on the optically smooth surface which can be obtained by the polishing of metal or glass. It may be concluded that there exists a special so-called Beilby state of the surface layer, which is supposed to be responsible for the disappearance of the phosphorescence of certain materials upon being finely ground and for the photosensitivity of silver iodide in the daguerretype process. It is further assumed that absorption forces are active in the polishing process.

**1284:** H. C. Hamaker: London-van der Waals forces in colloidal systems (Rec. trav. chim. Pays Bas **57,** 61 - 72, Jan. 1938).

The intensity and the sphere of action of London-van der Waals forces between spherical particles in colloidal systems are discussed in this article, cf. **1272.** The sphere of action is introduced as the distance at which the energy of reciprocal action is equal to the kinetic energy of the Brownian movement, and this is found to be 0.06 to 0.2 times the diameter of the smallest particle; the dimensions of the largest particle is of practically no importance. The adhesion forces observed under various conditions are found to be of the same order of magnitude as was expected theoretically. Our conception of the sphere of action depends upon the dimensions of the particles considered; different definitions of the sphere of action are compared with each other. It is found that a precise comparison of the observations of adhesive forces determined by different methods is only possible on the basis of a theoretical assumption about the nature of the active forces.

**1285*:** W. Uyterhoeven: Elektrische Gasentladungslampen; 364 pages, 1938. (Julius Springer, Berlin).

In this book the theoretical principles as well as the working characteristics of modern gas discharge lamps are treated as a whole in the simplest possible way for technicians who may have to do with these lamps in practice. After the more theoretical chapters on atomic theory and gas discharge, there follows a chapter on the characteristics of the radiation for illumination technique. In the fourth and fifth chapter the practical forms of construction are discussed for low and high pressure lamps respectively.

---

*) An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.

Published in April 1938:

Philips Transmitting News **5,** No. 1:

P. J. H. A. Nordlohne: The experimental short wave broadcasting station P.C.J.

Practical experience with the ultra-rapid action safety device for rectifier equipment, incorporating mercury-vapour valves.

Tj. Douma: Internal inductance of coils and its influence on the temperature coefficient of the coil.